



Final Report on Alternative Chromate-Free Wash Primers

**by Pauline Smith, Kestutis Chesonis, Christopher Miller,
and John Escarsega**

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14. ABSTRACT The purpose of the DOD-P-15328D wash primer is to enhance corrosion resistance, through the passivity of the metal surface. In the U.S. Army's Chemical Agent Resistant Coating (CARC) System, the metal surface is coated with a wash primer, over-coated with an epoxy primer, and followed by a camouflage urethane topcoat. Several coating procedures specify the use of wash primer DOD-P-15328D as a surface treatment prior to the application of an epoxy primer/polyurethane topcoat CARC system. The current wash primer is low-solids, solvent-based polyvinyl butyral that contains phosphoric acid and zinc chromate to promote adhesion and minimize corrosion. This coating contains large amounts of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) that impact coating operations due to air pollution regulations that may require the use of control devices to reduce the total VOC/HAP emissions to the atmosphere. The U.S. Army Research Laboratory has evaluated new, water-reducible wash primers that do not contain hexavalent chromium and significantly minimize potential VOC and HAP emissions during coating operations. Coatings have been extensively tested for accelerated corrosion and adhesion and have completed 3 years of outdoor exposure testing. Tests are now required on military equipment to validate the lab and controlled testing previously completed. The ultimate objective of the process is to demonstrate that the low-VOC wash primers can provide a "drop-in" solution to the environmental issues associated with the solvent-based primer currently in use, providing equal or better performance, involving no significant changes to the application and stripping procedures currently used. The field demonstration of this coating was conducted at Letterkenny Army Depot facility, prepared on an Engagement Control Station Patriot truck unit.					
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1. Introduction

At the beginning of the last century, cleaned steel surfaces were passivated by “washing” them with phosphoric acid solutions using sponges. In the 1930s, efforts to improve the uneven application of the acid led to the use of polyvinyl butyral resins and chromate pigments for inhibiting long-term corrosion. This technology became institutionalized during World War II when Union Carbide Corporation, under the direction of the U.S. Government, developed their wash primer, WP-1 (1), as a pretreatment for ship bottoms, with the patent assigned to the Secretary of the Navy. Their product evolved to the current specification, Department of Defense (DOD)-P-15328 (2). For items not capable of immersion in multiple solution systems, this specification has been used extensively by the U.S. Armed Forces to treat ferrous and nonferrous surfaces.

Specification DOD-P-15328 has a low-solids and high volatile organic compound (VOC) content, contains phosphoric acid, zinc chromate, and has hazardous air pollutants (HAPs). These characteristics come under the control of the National Ambient Air Quality Standards, Sections 109 and 112 of the Clean Air Act as amended in 1990. Over the years, the U.S. Army Research Laboratory (ARL) Coatings Technology Team has reformulated all of the camouflage chemical agent resistant coatings (CARC) and ammunition coatings to meet local and federal regulations. One of the most difficult tasks has been to reformulate the wash primer with reduced VOCs and zero HAPs that will have corrosion resistance similar to DOD-P-15328 without hexavalent chrome.

Wash primers are characteristically thin (0.3–0.5 mil [1 mil = 0.001 in]), cross-linked coatings applied directly to the substrate to provide protection from corrosion and promote adhesion (3). In the U.S. Army’s CARC System, the wash primer, DOD-P-15328, is over-coated with epoxy primer and camouflage polyurethane topcoat.

The CARC System application specification, MIL-C-53072 (4), requires that metal surfaces on tactical vehicles be treated to improve adhesion and corrosion resistance prior to coating with an epoxy primer and a camouflage topcoat. In original equipment manufacturer (OEM) processes, the surface treatment is generally performed by a five-stage dip process, e.g., zinc phosphate prescribed in TT-C-490 (5). In depot operations and for touch-ups in OEM processes, the surface treatment requirement is met through the wash primer, DOD-P-15328. The formulation contains 7.1% zinc chromate and has 6.5 lb/gal of VOCs which are classified as HAPs. Based on the estimated usage of 21,000 gal/year, the following pollution is generated annually: 12,600 lb of zinc chromate and 35,700 gal of package/thinner solvents (6). This large amount of VOCs and HAPs directly impacts coating operations due to air pollution regulations that may require the use of control devices to reduce the total emissions to the atmosphere. Because the pigmentation contains hexavalent chromium, the ARL Coatings Team has explored the use of

alternative passivation. The reasons for using hexavalent chromium substitutes are crucial—particularly for health, safety, environmental compliance, and pollution prevention.

Upon paint removal or stripping, the chromate wash primer, together with the CARC paint, generates hexavalent chromium-contaminated paint waste. This paint waste must be disposed as chromium-containing hazardous waste (7). Annually, ~6,000,000 lb of stripped CARC waste is produced. It costs ~\$0.61/lb to dispose of chromate-bearing paint waste, costing ~\$3,600,000 annually (8). It has been estimated that elimination of the chromate from the paint waste would eliminate the need to dispose of it as a hazardous waste, thereby reducing the disposal costs by two-thirds, for a savings of ~\$2,400,000 annually.

ARL has evaluated new water-reducible wash primers that do not contain hexavalent chromates and significantly minimize VOC- and HAP-potential emissions during coating operations. The new wash primers are water-borne acrylic latex emulsions with corrosion-inhibiting pigments. The three water-reducible acrylic latex emulsion formulations are designed for use under MIL-P-53030 (8), a water-reducible lead and chromate-free epoxy primer. The Coatings Technology Team prepared a 1200-panel matrix to evaluate these three formulations and two direct-to-metal (DTM) applications against the control specification.

2. Experimental

In this project, three vendor formulations were evaluated against the control DOD-P-15328. The initial effort consisted of evaluating various coating candidates in a laboratory environment and selecting a suitable candidate for field testing at a renovation facility. The selected coating candidate will be applied at a renovation facility to ensure the technical practicability. The control wash primer, DOD-P-15328, and the three potential replacement products were labeled, as shown in table 1.

Table 1. Control sample and replacement products.

D	DOD-P-15328D (control)
A	Aqua Zen by Hentzen
S	Kem Aqua by Sherwin Williams
R	RWE1033 by Spraylat
M	No pretreatment, modified primer by Niles (DTM)
P	No pretreatment, regular primer by Niles (DTM)

As shown in table 2, all substrates were coated with the water-reducible epoxy primer MIL-P-53030. The panels exposed in Florida and Arizona were topcoated with the green CARC MIL-C-46168 (9) Type IV topcoat CARC coatings. Two sets (M and P) labeled DTM were coated just with the epoxy primer and epoxy primer plus topcoat.

Table 2. Wash primer coating systems.

Substrate	Pretreatment	Primer	Topcoat
Cold rolled steel (CRS)1080	DOD-P-15328 or one of three vendors	MIL-P-53030 epoxy primer	MIL-C-46168 (2K polyurethane topcoat)
Aluminum (Al) 2024-T3	DOD-P-15328 or one of three vendors	MIL-P-53030	MIL-C-46168
Al 5083-H231	DOD-P-15328 or one of three vendors	MIL-P-53030	MIL-C-46168
Al 6061-T3	DOD-P-15328 or one of three vendors	MIL-P-53030	MIL-C-46168
Al 7075-T6	DOD-P-15328 or one of three vendors	MIL-P-53030	MIL-C-46168

DOD-P-15328 and the three potential replacement products were applied to five different surfaces, as shown in table 3—cold rolled steel (CRS) Type R 1080 panels ($4 \times 6 \times 0.032$ in) and aluminum panels of alloys 2024-T3, 5083-H231, 6061-T3, and 7075-T6, at the recommended film thickness. Prior to pretreatment and testing, the panels were labeled mechanically to permanently affix the proper designation.

Table 3. Substrate codes used for testing.

1	CRS 1080	$4 \times 6 \times 0.032$ in
2	Al 2024-T3	$4 \times 6 \times 0.032$ in
5	Al 5083-H231	$4 \times 6 \times 0.25$ in
6	Al 6061-T3	$4 \times 6 \times 0.063$ in
7	Al 7075-T6	$4 \times 6 \times 0.032$ in

Before painting, all panels were cleaned and the pretreatments were applied per manufacturer's specification. The manufacturer's recommended thicknesses are continued in table 4. The heavy thickness mentioned in table 5 is double the recommended thickness. The test specimens were horizontally oriented during paint application. A conventional air-atomizing spray gun was used to apply the candidate wash primer to the appropriate substrates. Because the three vendor samples were emulsion-type systems, quite different from the control wash primer, two variations in the application of the coatings were performed. The first variation was to overcoat the wash primers after 1 hr and after 24 hr of drying time for the wash primer, a scenario that could easily occur at the depots (table 5). The second variation was to apply the recommended film thickness of the wash primer and to also apply a heavier coat of the wash primer (table 4). The full coating systems were allowed to cure at ambient temperature (~ 75 °F) and humidity for 7 days. Table 6 is a schematic detailing the test matrix.


Table 4. Dry film thickness codes.

D	DOD-P-15328D	0.5–1.0 mil
A	Aqua Zen by Hentzen Paints	0.3–0.5 mil
S	Kem Aqua by Sherwin Williams Company	0.3–0.5 mil
R	RWE-1033 by Spraylat Corporation	0.2–0.4 mil

Table 5. Codes for application and recoat schedule.

1	Normal thickness	1 hr before primer application
2	Normal thickness	24 hr before primer application
3	Heavy thickness	1 hr before primer application
4	Heavy thickness	24 hr before primer application

Table 6. Test matrix.

Alloys	Pretreatments	Application	Test Method	Coupons
1080 Steel	DoD-P-15328	Thin @ 1 Hour	Outdoor Exposure (FL)	
2024 Al	Kem Aqua	Thin @ 24 Hours	Outdoor Exposure (AZ)	
5083 Al	Aqua Zen	Thick @ 1 Hour	ASTM B 117	
6061 Al	Spraylat RWE 1033	Thick @ 24 Hours	GM 9540P	
7075 Al	Direct to Metal (DTM)		ASTM D 3359	

3. Results and Discussion

The newly developed wash primer replacements have been extensively tested for accelerated corrosion and adhesion and have completed 42 months of outdoor exposure testing. Thus far, results are very specific to the substrate in terms of blistering and fading. ARL will conduct tests on actual equipment to validate the lab testing previously completed. Efforts are underway to field-evaluate these alternatives to actual equipment in order to validate the application and durability of these products. Successful completion of this test effort will lead to a revision of DOD-P-15328 and provide a qualified products list (QPL) for the new product(s). Additionally, revision of MIL-P-53030 to match the performance characteristics of new products currently in development will correspond with this initiative.

3.1 Spraying Properties

All three potential replacement products sprayed uniform films without any surface defects. The laboratory addressed two separate failure criteria by varying film thickness and drying time before primer application.

3.2 Water Immersion Resistance

The American Society for Testing and Materials (ASTM) D 1308 (10) requires exposing an organic coating to a reagent to determine adverse affects. Panels of wash primers and epoxy primers were immersed to half of the panel length in deionized water at room temperature (23 ± 5 °C) for 7 days. Immediately upon removal, and after a 24-hr recovery period, the panels were examined for any defects, such as blistering, loss of adhesion, color, and gloss change. All panels passed the water immersion test.

3.3 Flexibility

The mandrel bend test was performed on all coatings in accordance with ASTM D 522 (11). The purpose of this test was to assess each coating's resistance to cracking and rate their flexibility. Due to panel thickness, Al-6061-T3 and Al-7075-T6 alloys were not tested.

3.4 Impact Resistance

The standard test for resistance to deformation (impact) was performed using a Gardner height-impact tester that consists of a vertical guide tube and a cylindrical weight that is dropped on a punch resting on the test panel. Impact resistance can be described as a paint property that quantitatively characterizes the adhesion and flexibility of a coating with respect to a rapid impact event. After curing 7 days at ambient laboratory conditions, the impact-resistance test, based on ASTM D 2794 (12), was performed on all coatings using 40 in-lb weights. All selected coatings passed using the 40 in-lb weights, with minor distinctions when impact was increased to 80 in-lb. Results are listed in table 7. A-6061-T3 and Al-7075-T3 were not tested due to panel dimensions.

3.5 Dry Adhesion Testing (ASTM D 3359 Method B Adhesion Testing) (13)

Table 8 lists the panels used in adhesion testing and the results. The ASTM cross-cut adhesion testing was performed with 2-mm line spacing, appropriate for dry film thickness between 2 and 5 mil (1 mil = 0.001 in).

3.6 Wet Adhesion Testing

All of the samples were immersed in water for 7 days and subjected to cross-cut adhesion testing. Upon removal and after a 24-hr recovery period, the samples were evaluated for blistering, softening, and loss of adhesion. Table 9 lists the panels used in adhesion testing and their results, which were read using ASTM 3359 Method B standards.

Table 7. Results of impact resistance.

	360 Days Ambient	GM 9540 100 Cycles + 360 Days Ambient
Panel	Reverse Impact (80 in-lb)	Reverse Impact (80 in-lb)
1M	2	2
1P	2	2
1D	2	1
1R	5	5
1A	5	5
1S	2	3
6M	1	—
6P	1	—
6D	2	—
6R	5	—
6A	5	—
6S	2	—
7M	2	—
7P	2	—
7D	3	—
7R	5	—
7A	5	—
7S	3	—
	Reverse Impact (40 in-lb)	Reverse Impact (40 in-lb)
2M	2	4
2P	1	4
2D	*3	*3
2R	5	5
2A	5	4
2S	4	3

Notes: rating criteria:

1 = 80%–90% removal of coating/large popping.

2 = 70%–80% removal of coating.

3 = 60%–70% removal of coating.

4 = 10% removal/cracking.

5 = <5% removal of coating.

* = average values.

Table 8. Dry adhesion testing.

Pretreatment	CRS 1080	Al 2024-T3	Al 5083-H231	Al 6061-T3	Al 7075-T6
Aqua Zen	5B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
DOD-P-15328D	5B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
Kem Aqua (K)	4B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
RWE-1033	5B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
Kem Aqua (S)	5B (pass)	4B (pass)	5B (pass)	5B (pass)	5B (pass)
MIL-P-53022-10 w/additive	2B (fail)	1B (fail)	1B (fail)	4B (pass)	3B (fail)
MIL-P-53022-10 direct to metal	5B (pass)	2B (fail)	1B (fail)	3B (fail)	2B (fail)

Notes:





Classification	Surface of cross-cut area from which flaking has occurred. (Example for 6 parallel cuts)
5	None
4	
3	
2	
1	

Table 9. Wet adhesion testing.

Pretreatment	CRS 1080	Al 2024-T3	Al 5083-H231	Al 6061-T3	Al 7075-T6
Aqua Zen	5B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
DOD-P-15328D	5B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
Kem Aqua (K)	4B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
RWE-1033	5B (pass)	5B (pass)	5B (pass)	5B (pass)	5B (pass)
Kem Aqua (S)	5B (pass)	4B (pass)	5B (pass)	5B (pass)	5B (pass)
MIL-P-53022-10 w/additive	2B (fail)	2B (fail)	1B (fail)	1B (fail)	4B (pass)
MIL-P-53022-10 direct to metal	5B (pass)	1B (fail)	1B (fail)	1B (fail)	1B (fail)

3.7 Accelerated Corrosion Resistance

Accelerated corrosion testing was performed using both a neutral salt spray test per ASTM B 117 (14) and an accelerated cyclic corrosion test per General Motors (GM) 9540P (15). Salt-spray resistance is widely used by the paint industry as a quality control test and is not necessarily indicative of long-term performance of a coating. Exposure to salt fog provides information about diffusion and porosity of the coating. Prior to exposure, the panels for each system were scribed with two intersecting scribes (“X”) through the coatings to the substrate.

The panels were X-scribed using a standard carbide-tipped hardened steel scribe. The painted panels (three each) for each coating were exposed to neutral salt fog at a temperature of 95 °F and saturated humidity (5% sodium chloride). The test panels were rated for damage at weekly intervals and inspected at 500-hr intervals for up to 2088 hr of salt spray. All of the painted panels appeared visually identical before testing. Panels were evaluated using ASTM D 1654 (16) for “Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments” and ASTM D 714-87 (17) for “Standard Test Method for Evaluating Degree of Blistering of Paints.” Final detailed ratings for the 2088-hr duration using ASTM D 1654 quantitatively indicated the damage caused by pitting or delamination outward from the scribe.

GM 9540P is an accelerated cyclic corrosion test that was developed by the automotive industry to determine long-term outdoor performance of coatings more accurately than the conventional salt spray test. It evaluates adhesion as well as corrosion of the system over time. A cyclic corrosion test chamber (CCTC) was used to perform the GM 9540P test. The test consisted of the repetition of one cycle with 18 separate stages including salt (1.25% by mass: 0.9% NaCl, 0.1% CaCl₂, and 0.25% NaHCO₃) water mist, humidity, drying, ambient, and heated drying. This process repeated 80 times to a scribed panel is claimed by industry to be equivalent to 10 years of field exposure in South Florida for their specific coating systems. For this test, the groups of scribed coupons were exposed until failure or completion of 100 cycles. In addition, standard plain carbon steel calibration coupons described in GM 9540P, and supplied by GM, were initially weighed and subsequently monitored for mass loss at intervals set by the specification. Mass losses measured for steel coupons used for this test were within parameters stated in the GM 9540P specification. For each coating tested, three panels were subjected to CCTC testing. As in salt spray, the panels were X-scribed.

The criteria for failure was creep from scribe of >10 mm (ASTM D 1654 rating of <3). Upon removal and prior to evaluation, coupons were rinsed in deionized water, and scraped at a 30° contact angle to the test surface with a blunt-edged, metal knife. Once scraped, the test panels were removed from other corrosion testing.

Al 2024-T3 is mainly used on aircraft and missiles and is the least corrosion resistant of the series. For Al 2024-T3, as shown in table 10, the alternative systems have 40–60% of the control protection after 1088 hr in salt fog, while DTM has 10%, and at 2088 hr, DTM has 0% protection. At 44 cycles in the GM 9540P, the control offers 90% protection, while the three alternative systems offer ~50%, and the DTM offers ~10%. The separation between 44 cycles and 100 cycles was marginal.

Table 10. Average rating for creep from scribe for Al 2024-T3.

	ASTM B 117		GM 9540P	
Al 2024-T3	1088 hr	2088 hr	44 Cycles	100 Cycles
2D1	10.00	9.33	9.33	8.00
2D2	9.33	8.00	7.00	5.00
2D3	9.33	9.33	7.66	6.00
2D4	9.00	9.00	6.66	5.67
Avg D	9.42	8.92	7.66	6.17
2A1	5.67	0.00	7.67	4.33
2A2	6.00	4.33	6.66	3.67
2A3	5.00	4.67	7.00	4.33
2A4	6.00	3.67	5.66	3.00
Avg A	5.67	3.00	6.75	3.83
2S1	4.00	0.33	5.33	4.67
2S2	6.00	1.00	5.33	3.33
2S3	6.00	1.00	6.00	4.67
2S4	6.00	1.00	6.00	4.67
Avg S	4.15	3.58	5.67	4.34
2R1	3.33	9.33	6.00	6.00
2R2	2.67	9.00	5.66	5.00
2R3	4.67	10.00	5.66	5.00
2R4	4.00	7.67	5.00	4.00
Avg R	3.67	3.30	5.58	5.00
2M2	1.00	0.00	1.00	0.00
2M4	0.00	0.00	2.67	0.00
Avg M	0.00	0.00	1.84	0.00
2P2	1.67	0.00	3.00	2.66
2P4	0.60	0.00	3.00	2.66
Avg P	1.14	0.00	3.00	2.66

Al 5083-H231 does well in corrosion due to its protective oxide layer and is normally utilized on armor and tactical ground systems. In table 11, the slight change in data from 44 to 100 cycles in the GM chamber shows that two vendors are equal to the control. In ASTM B 117, the DTM offered 30% protection over the control after 2088 hr.

Table 11. Average ratings for creep from scribe for Al 5083-H231.

Al 5083-H231	ASTM B 117		GM 9540P	
	1088 hr	2088 hr	44 Cycles	100 Cycles
5D1	9.33	9.00	10.00	10.00
5D2	9.00	9.00	9.67	9.33
5D3	9.00	9.00	9.67	9.67
5D4	9.00	9.00	9.33	9.00
Avg D	9.08	9.00	9.67	9.50
5A1	7.00	6.60	9.00	9.00
5A2	7.67	7.62	9.00	9.00
5A3	9.00	9.00	9.00	9.00
5A4	9.00	9.00	9.00	9.00
Avg A	8.17	8.06	9.00	9.00
5S1	9.00	9.00	8.33	8.00
5S2	7.67	7.00	8.00	7.67
5S3	9.00	9.00	7.00	7.00
5S4	7.67	7.33	9.00	9.00
Avg S	4.15	8.08	8.08	7.92
5R1	9.67	9.33	9.33	9.00
5R2	9.33	9.33	9.00	7.67
5R3	10.00	10.00	9.00	8.67
5R4	9.33	9.00	9.33	8.67
Avg R	9.58	3.30	9.17	8.50
5M2	3.33	2.67	6.33	5.33
5M4	5.00	4.33	5.33	0.00
Avg M	0.00	0.00	5.83	0.00
5P2	3.33	2.00	5.33	5.33
5P4	5.33	4.67	6.00	5.67
Avg P	4.33	3.34	5.67	5.50

Al 6061-T3 is mainly used on components, and, as seen in table 12, all of the pretreatments performed well on Al 6061, showing little or no damage to the scribed region. DTM has 0% protection at 44 and 100 cycles, while the three vendors and the control offer 90% of corrosion protection. Additionally, the salt-fog environment demonstrates that the three vendors and the control provide 90% protection, while the DTM offers 50%.

Most pretreatments on Al 7075-T6 performed well, with little or no damage to the scribed region. The top performers are clearly visible in table 13. Except for the DTM, all pretreatment surfaces had very minute creepage or corrosion.

The coated steel panels performed differently from the aluminum alloys, showing greater rust and surface corrosion. The distinction is shown in table 14 for 1000 hr in salt fog, where the three vendors and the DTM are inferior to the control.

Table 12. Average ratings for creep from scribe of Al 6061-T3.

	ASTM B 117		GM 9540P	
Al 6061-T3	1080 hr	2088 hr	44 Cycles	100 Cycles
6D1B	9.00	9.00	10.00	9.00
6D2B	9.00	9.00	10.00	9.00
6D3B	9.00	10.00	10.00	9.00
6D4B	9.00	10.00	9.00	9.00
Avg D	9.20	9.50	9.80	9.20
6A1B	7.00	9.00	10.00	9.00
6A2B	9.00	9.00	10.00	6.00
6A3B	8.00	8.00	10.00	10.00
6A4B	9.00	8.00	10.00	9.00
Avg A	8.25	8.50	10.00	8.50
6R1B	10.00	10.00	10.00	4.00
6R2B	10.00	10.00	10.00	8.00
6R3B	9.00	9.00	10.00	9.00
6R4B	9.00	9.00	10.00	9.00
Avg R	9.50	9.50	10.00	7.50
6S1B	8.00	4.00	9.00	4.00
6S2B	9.00	9.00	9.00	0.00
6S3B	9.00	6.00	9.00	3.00
6S4B	9.00	6.00	9.00	3.00
Avg S	8.75	6.25	9.00	2.50
6M2B	4.00	0.00	3.00	0.00
5M4B	3.00	0.00	6.00	0.00
Avg M	3.50	0.00	4.50	0.00
6P2B	6.00	0.00	3.00	0.00
6P4B	6.00	0.00	4.00	4.00
Avg P	6.00	0.00	3.50	2.00

Table 13. Average ratings for creep from scribe of Al 7075-T6.

	ASTM B 117		GM 9540P	
Al 7075-T6	1080 hr	2088 hr	44 Cycles	100 Cycles
7D1B	10.00	9.00	10.00	9.00
7D2B	9.00	9.00	10.00	9.00
7D2B	9.00	9.00	9.00	9.00
7D3B	10.00	10.00	10.00	10.00
7D4B	9.00	9.00	9.00	9.00
Avg D	9.40	9.20	9.60	9.20
7A1B	10.00	9.00	10.00	9.00
7A2B	9.00	9.00	10.00	9.00
7A3B	10.00	10.00	10.00	10.00
7A4B	9.00	9.00	9.00	9.00
Avg A	9.50	9.25	9.75	9.25
7R1B	9.00	9.00	10.00	9.00
7R2B	9.00	9.00	10.00	9.00
7R3B	10.00	10.00	10.00	10.00
7R4B	9.00	9.00	9.00	9.00

Table 13. Average ratings for creep from scribe of Al 7075-T6 (continued).

	ASTM B 117		GM 9540P	
Al 7075-T6	1080 hr	2088 hr	44 Cycles	100 Cycles
Avg R	9.25	9.25	9.75	9.25
7S1B	9.00	9.00	9.00	9.00
7S2B	7.00	6.00	7.00	6.00
7S3B	9.00	9.00	9.00	9.00
7S4B	7.00	6.00	7.00	6.00
Avg S	8.00	7.50	8.00	7.50
7M2B	3.00	2.00	3.00	2.00
7M4B	4.00	3.00	6.00	3.00
Avg M	3.50	2.50	4.00	2.50
7P2B	2.00	2.00	3.00	2.00
7P4B	7.00	6.00	7.00	5.00
Avg P	4.50	3.50	5.00	3.50

Table 14. Average ratings for creep from scribe for CRS 1080.

	ASTM B 117		GM 9540P	
CRS 1080	1080 hr	2088 hr	44 Cycles	100 Cycles
1D1	3.33	2.33	—	—
1D2	4.67	3.33	4.67	3.00
1D3	4.33	2.33	5.00	3.00
1D4	5.00	4.00	5.00	4.33
Avg D	4.33	3.00	4.89	3.44
1A1	3.00	0.00	4.33	1.67
1A2	2.00	0.00	4.33	1.67
1A3	1.33	0.67	4.67	2.00
1A4	5.33	2.00	4.33	2.67
Avg A	2.92	2.10	4.42	2.50
1S1	3.33	3.33	2.67	0.00
1S2	4.33	4.00	3.33	0.00
1S3	4.67	3.33	3.00	1.00
1S4	4.30	3.67	3.00	0.33
Avg S	4.15	3.58	3.00	1.00
1R1	3.33	1.00	5.00	4.00
1R2	2.67	2.00	5.00	3.67
1R3	4.67	3.33	5.00	3.00
1R4	4.00	2.33	4.33	3.33
Avg R	3.67	3.30	4.83	3.50
1M2	0.00	0.00	1.00	0.00
1M4	0.00	0.00	2.67	0.00
Avg M	0.00	0.00	1.84	0.00
1P2	1.67	0.00	3.67	0.00
1P4	3.00	0.67	3.67	0.33
Avg P	2.34	0.34	3.67	0.17

For the GM 9540P specification, 100 cycles was the best separator, with the DTM providing 0% protection. Therefore, the better performers on steel were easily observed. Most films were intact outside the scribed areas. The four treated surfaces showed similar corrosion degradation at the scribed areas and no evidence of blisters. The untreated surface (DTM) showed 90% delamination of the panel. Figures 1–6 show examples of samples exposed in both chambers.

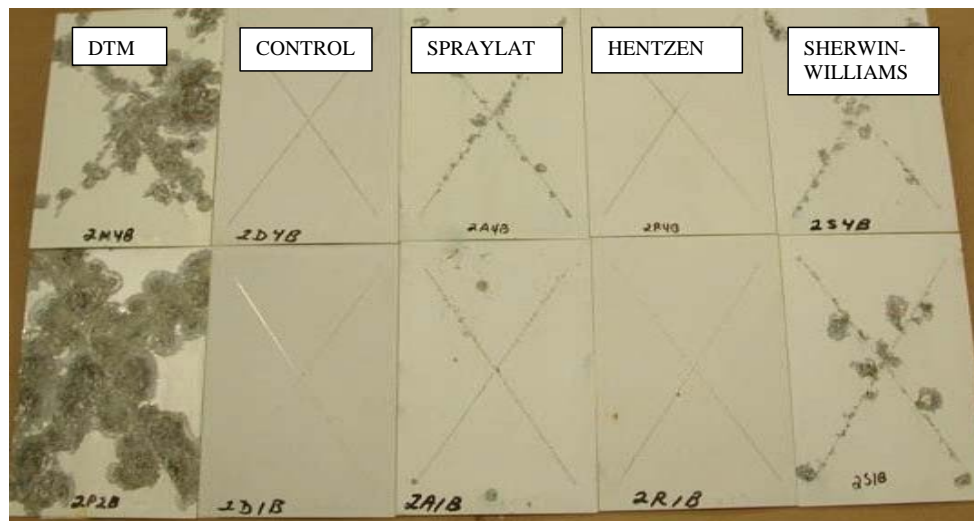


Figure 1. GM 9540P results for Al 2024-T3.

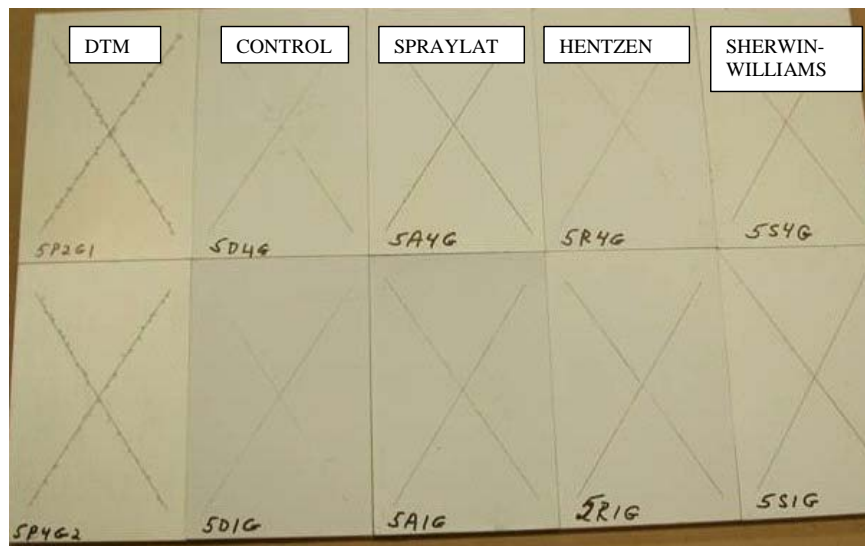


Figure 2. GM 9540P results for Al 5083-H231.

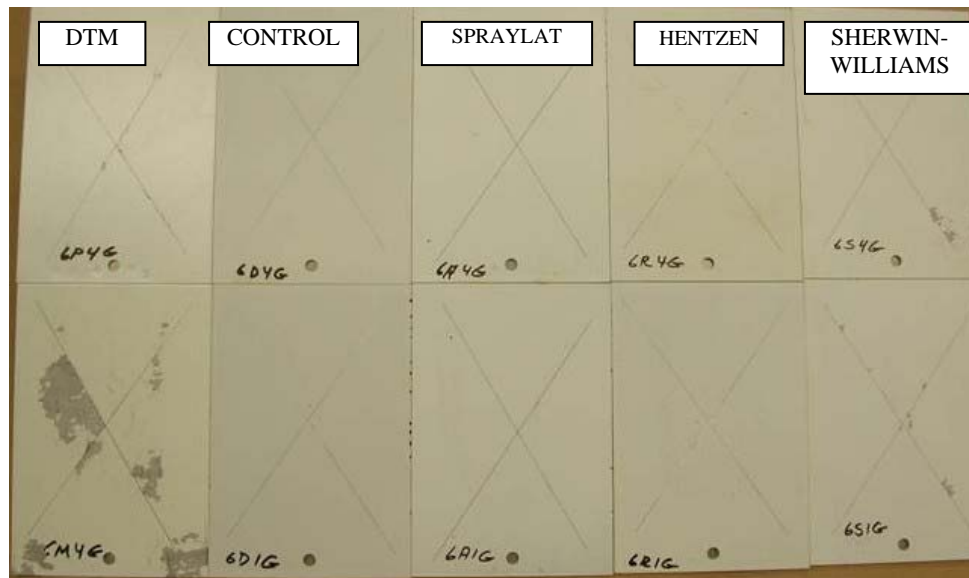


Figure 3. GM 9540P results on Al 6061-T3.

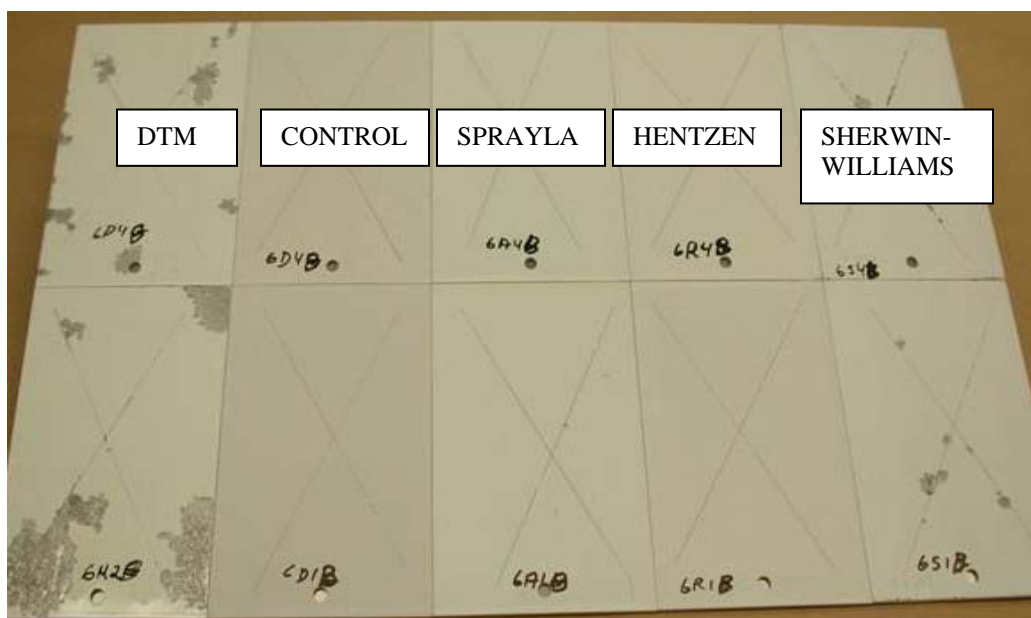


Figure 4. ASTM B 117 results on Al 6061-T3.

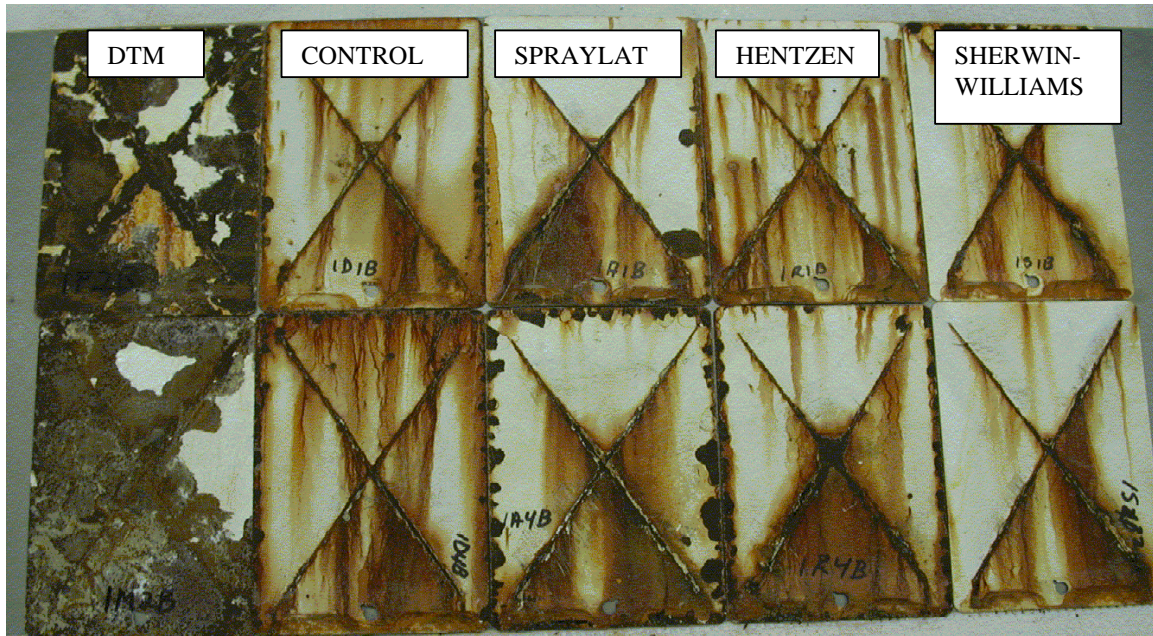


Figure 5. ASTM B 117 results on CRS 1080.

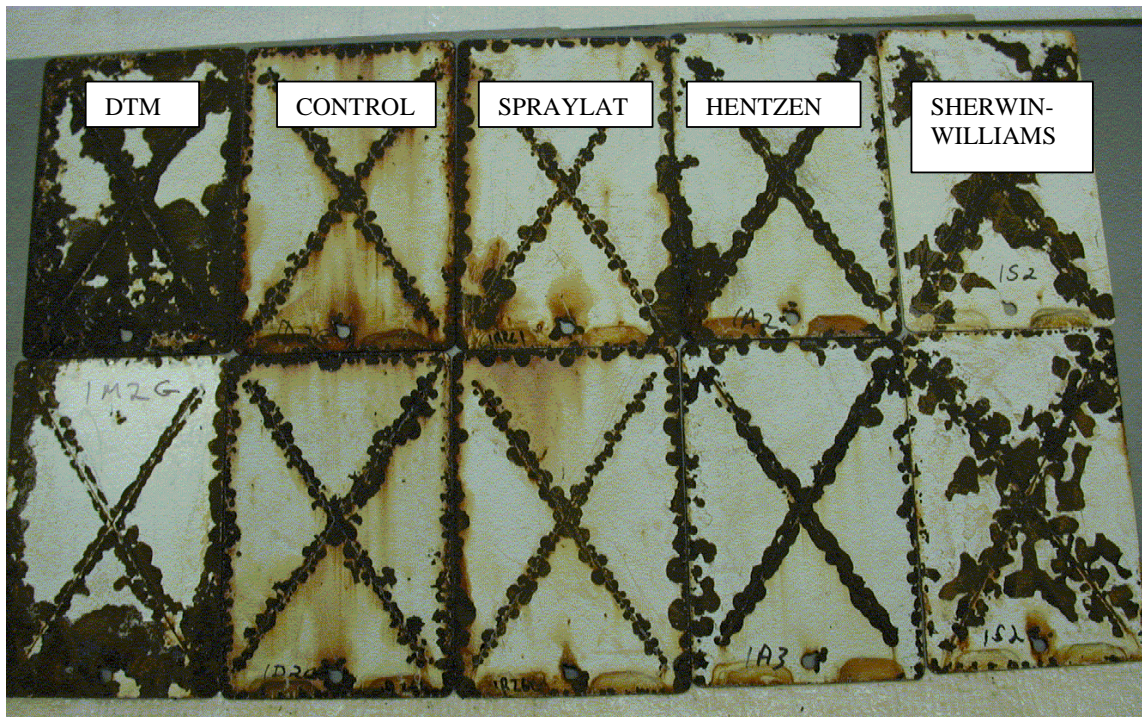


Figure 6. GM 9540P results on CRS 1080.

3.8 Outdoor Weathering in Florida and Arizona Exposure

3.8.1 South Florida Exposure

The outdoor exposure testing was performed at the Miami, FL, site (26° N), at a tilt of 5° from the horizontal facing south. The samples were mounted on an aluminum rack, with the coated side facing the sun. The total radiant energy was measured at 12,384.16 MJ/m², 295,988 Langley, and the ultraviolet measured at 525.23 MJ/m².

3.8.2 South Florida Exposure at 3 Months

Table 15 summarizes the results after 3 months of exposure, with visual color change, face rust, cracking, blistering, and delamination all rated at 10 for all, where 10 = no change. There were no changes in the samples except that all the samples on steel showed signs of scribe rust. There were no failures after 3 months of exposure.

Table 15. Florida exposure at 3 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	10	10	10	10	9	10
1D	10	10	10	10	9	10
1M	10	10	10	10	9	10
1P	10	10	10	10	9	10
1R	10	10	10	10	9	10
1S	10	10	10	10	9	10
2A	10	10	10	10	10	10
2D	10	10	10	10	10	10
2M	10	10	10	10	10	10
2P	10	10	10	10	10	10
2R	10	10	10	10	10	10
2S	10	10	10	10	10	10
5A	10	10	10	10	10	10
5D	10	10	10	10	10	10
5M	10	10	10	10	10	10
5P	10	10	10	10	10	10
5R	10	10	10	10	10	10
5S	10	10	10	10	10	10

3.8.3 South Florida Exposure at 6 Months

Table 16 summarizes the results after 6 months of exposure. The visual color change was either 7f or 8f, where 7 = slight to moderate, 8 = slight, and f = fade. Face rust, cracking, blistering, and delamination were all constant at 10. The color rating decreased in each sample, and the scribe rust on the steel samples either decreased or remained the same at 9. There were no failures after 6 months of exposure.

Table 16. Florida exposure at 6 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	7f	10	10	10	8	10
1D	7f	10	10	10	8.1	10
1M	7f	10	10	10	8.2	10
1P	7f	10	10	10	8.2	10
1R	7f	10	10	10	9	10
1S	7f	10	10	10	9	10
2A	7f	10	10	10	10	10
2D	7f	10	10	10	10	10
2M	7f	10	10	10	10	10
2P	7f	10	10	10	10	10
2R	7f	10	10	10	10	10
2S	7f	10	10	10	10	10
5A	8f	10	10	10	10	10
5D	8f	10	10	10	10	10
5M	8f	10	10	10	10	10
5P	8f	10	10	10	10	10
5R	8f	10	10	10	10	10
5S	8f	10	10	10	10	10

3.8.4 South Florida Exposure at 9 Months

Table 17 summarizes the results after 9 months of exposure. The color changes range from 6f to 8f, where 6 = moderate, 7 = slight to moderate, 8 = slight, and f = fade. Face rust, cracking, blistering, and delamination were all constant at 10. The color change of the steel samples either became more noticeable, which decreased its rating to 6f, or remained the same at either 7f or 8f. The scribe rust on the steel samples also either decreased or remained the same. There were no failures after 9 months of exposure.

Table 17. Florida exposure at 9 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	6f	10	10	10	8	10
1D	6f	10	10	10	8	10
1M	7f-6f	10	10	10	8.2	10
1P	6f-7f	10	10	10	9	10
1R	7f	10	10	10	9	10
1S	7f	10	10	10	9	10
2A	7f	10	10	10	10	10
2D	7f	10	10	10	10	10
2M	7f	10	10	10	10	10
2P	7f	10	10	10	10	10
2R	7f	10	10	10	10	10
2S	7f	10	10	10	10	10
5A	8f	10	10	10	10	10
5D	8f	10	10	10	10	10
5M	8f	10	10	10	10	10
5P	8f	10	10	10	10	10
5R	8f	10	10	10	10	10
5S	8f	10	10	10	10	10

3.8.5 South Florida Exposure After 12 Months

Table 18 summarizes the results after 12 months of exposure. The visual color change was rated at 4f for all. Blistering was noted and graded either 6f or 10, where 6 = blister size of 1 mm, f = few, and 10 = none. The face rust, cracking, and delamination were all constant at 10, where 10 = no change. The color change in the samples became very evident after 12 months of exposure, dropping to 4f.

After 12 months of exposure, 10 of the 12 CRS 1080 panels treated with Aqua Zen by Hentzen, three of 12 CRS 1080 control panels, two of 12 CRS 1080 panels treated with RWE1033 by Spraylat, and 11 of 12 CRS 1080 panels treated with KemAqua by Sherwin Williams failed the blistering tests with ratings of 6f. In addition, all of the steel panels failed the scribe rust testing after 12 months of exposure.

Table 18. Florida exposure at 12 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	4f	10	10	6.7	2	10
1D	4f	10	10	9	2	10
1M	4f	10	10	10	2	10
1P	4f	10	10	10	2	10
1R	4f	10	10	9.3	2	10
1S	4f	10	10	6.3	2	10
2A	4f	10	10	10	10	10
2D	4f	10	10	10	10	10
2M	4f	10	10	10	10	10
2P	4f	10	10	10	10	10
2R	4f	10	10	10	10	10
2S	4f	10	10	10	10	10
5A	4f	10	10	10	10	10
5D	4f	10	10	10	10	10
5M	4f	10	10	10	10	10
5P	4f	10	10	10	10	10
5R	4f	10	10	10	10	10
5S	4f	10	10	10	10	10

3.8.6 South Florida Exposure After 15 Months

Table 19 summarizes the results after 15 months of exposure. The visual color change was rated at 4f for all.

The results after 15 months of exposure mirrored the results after 12 months of exposure, except the scribe rust rating on the CRS 1080 panels increased in some of the panels from 2.03 to 2.06. Face rust, cracking, and delamination were all constant at 10, where 10 = no change.

Table 19. Florida exposure at 15 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	4f	10	10	6.7	2.1	10
1D	4f	10	10	9	2.1	10
1M	4f	10	10	10	2.1	10
1P	4f	10	10	10	2.1	10
1R	4f	10	10	9.3	2	10
1S	4f	10	10	6.3	2	10
2A	4f	10	10	10	10	10
2D	4f	10	10	10	10	10
2M	4f	10	10	10	10	10
2P	4f	10	10	10	10	10
2R	4f	10	10	10	10	10
2S	4f	10	10	10	10	10
5A	4f	10	10	10	10	10
5D	4f	10	10	10	10	10
5M	4f	10	10	10	10	10
5P	4f	10	10	10	10	10
5R	4f	10	10	10	10	10
5S	4f	10	10	10	10	10

3.8.7 South Florida Exposure After 18 Months

Table 20 summarizes the results after 18 months of exposure. The visual color change was rated at 4f for all. Blistering was noted and graded ranging from 6f to 10. The face rust, cracking, and delamination all remained constant at 10.

The results after 18 months of exposure were an exact replica of the results after 15 months of exposure.

Table 20. Florida exposure at 18 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	4f	10	10	6.7	2.1	10
1D	4f	10	10	9	2.1	10
1M	4f	10	10	10	2.1	10
1P	4f	10	10	10	2.1	10
1R	4f	10	10	9.3	2	10
1S	4f	10	10	6.3	2	10
2A	4f	10	10	10	10	10
2D	4f	10	10	10	10	10
2M	4f	10	10	10	10	10
2P	4f	10	10	10	10	10
2R	4f	10	10	10	10	10
2S	4f	10	10	10	10	10
5A	4f	10	10	10	10	10
5D	4f	10	10	10	10	10
5M	4f	10	10	10	10	10
5P	4f	10	10	10	10	10
5R	4f	10	10	10	10	10
5S	4f	10	10	10	10	10

3.8.8 South Florida Exposure After 21 Months

Table 21 summarizes the results after 21 months of exposure. The visual color change was rated at 4f for all. Blistering was noted and graded ranging from 6f to 10. The delamination was constant at 10, where 10 = none, with the exception of 2P, which had a delamination between 6 and 8 equal to 6.66, where 6 = pronounced and 8 = slight. Face rust and cracking were all constant at 10.

The results after 21 months of exposure remained the same as the results after 18 months of exposure, with one exception in regard to the delamination testing. After 21 months of exposure, five of six AI 2024-T3 panels treated with the regular primer DTM failed the delamination testing with ratings from 3 to 9, which gives an average delamination rating equal to 6.66.

Table 21. Florida exposure at 21 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	4f	10	10	6.7	2.1	10
1D	4f	10	10	9	2.1	10
1M	4f	10	10	10	2.1	10
1P	4f	10	10	10	2.1	10
1R	4f	10	10	9.3	2	10
1S	4f	10	10	6.3	2	10
2A	4f	10	10	10	10	10
2D	4f	10	10	10	10	10
2M	4f	10	10	10	10	10
2P	4f	10	10	10	10	6.7
2R	4f	10	10	10	10	10
2S	4f	10	10	10	10	10
5A	4f	10	10	10	10	10
5D	4f	10	10	10	10	10
5M	4f	10	10	10	10	10
5P	4f	10	10	10	10	10
5R	4f	10	10	10	10	10
5S	4f	10	10	10	10	10

3.8.9 South Florida Exposure After 24 Months

Table 22 summarizes the results after 24 months of exposure. The visual color change was rated at 4f for all. Blistering was noted and graded ranging from 6f to 10. The delamination was constant at 10, where 10 = none, with the exception of panel 2P which had a delamination of 6, where 6 = moderate.

Face rust and cracking were all constant at 10. The results after 24 months of exposure mimicked the results after 21 months of exposure. With the exception of a slight decrease in the delamination rating of the AI 2024-T3 panels treated with regular DTM. Five of the six panels received ratings from 3 to 9, for a value of 6.66 after 21 months. However, after 24 months, five of the six panels failed the testing with ratings from 2 to 8, for a delamination value of 6.

Table 22. Florida exposure at 24 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	4f	10	10	6.7	2.1	10
1D	4f	10	10	9	2.1	10
1M	4f	10	10	10	2.1	10
1P	4f	10	10	9.3	2.1	10
1R	4f	10	10	6.3	2	10
1S	4f	10	10	10	2	10
2A	4f	10	10	10	10	10
2D	4f	10	10	10	10	10
2M	4f	10	10	10	10	10
2P	4f	10	10	10	10	6
2R	4f	10	10	10	10	10
2S	4f	10	10	10	10	10
5A	4f	10	10	10	10	10
5D	4f	10	10	10	10	10
5M	4f	10	10	10	10	10
5P	4f	10	10	10	10	10
5R	4f	10	10	10	10	10
5S	4f	10	10	10	10	10

Corrosion and blisters were noted on the pretreated steel substrate and graded 6f. Samples 1M, 1P, 1R, and 1S had severe creep from the scribe.

3.8.10 South Florida Exposure After 27 Months

Table 23 summarizes the results after 27 months of exposure. The visual color change was rated as either 3f or 4f. Blistering was noted and graded ranging from 6f to 10. Delamination readings were constant at 10, with the exception of specimen 2P, which had a delamination of 5, where 5 = moderate to pronounced.

Overall, the results after 27 months were the same in the areas of face rust, cracking, blisters, and scribe rust. However, in the area of color change, the steel panels remained the same, but the color change rating for the rest of the panels decreased from 4f to 3f. Also, in the delamination readings, the value for Al 2024-T3 panels treated with the regular primer DTM decreased from five of the six panels with ratings from 2 to 8, for a delamination value of 6, to five of six panels with ratings of 2 to 7, for a delamination value equal to 5.

3.8.11 South Florida Exposure After 30 Months

Table 24 summarizes the results after 30 months of exposure. The visual color change was rated at either 3f or 4f. Blistering was noted and graded ranging from 6f–10. Delamination was constant at 10, except for specimen 2M, which had a delamination of 9.5, where 9.5 = slight to none, and specimen 2P, which had a delamination of 4.5, where 4.5 = moderate to pronounced.

Table 23. Florida exposure at 27 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	4f	10	10	6.7	2.1	10
1D	4f	10	10	9	2.1	10
1M	4f	10	10	10	2.1	10
1P	4f	10	10	10	2.1	10
1R	4f	10	10	9.3	2	10
1S	4f	10	10	6.3	2	10
2A	3f	10	10	10	10	10
2D	3f	10	10	10	10	10
2M	3f	10	10	10	10	10
2P	3f	10	10	10	10	5
2R	3f	10	10	10	10	10
2S	3f	10	10	10	10	10
5A	3f	10	10	10	10	10
5D	3f	10	10	10	10	10
5M	3f	10	10	10	10	10
5P	3f	10	10	10	10	10
5R	3f	10	10	10	10	10
5S	3f	10	10	10	10	10

Table 24. Florida exposure at 30 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	4f	10	10	6.7	2.1	10
1D	4f	10	10	9	2.1	10
1M	4f	10	10	10	2.1	10
1P	4f	10	10	10	2.1	10
1R	4f	10	10	9.3	2	10
1S	4f	10	10	6.3	2	10
2A	3f	10	10	10	10	10
2D	3f	10	10	10	10	10
2M	3f	10	10	10	10	9.5
2P	3f	10	10	10	10	4.5
2R	3f	10	10	10	10	10
2S	3f	10	10	10	10	10
5A	3f	10	10	10	10	10
5D	3f	10	10	10	10	10
5M	3f	10	10	10	10	10
5P	3f	10	10	10	10	10
5R	3f	10	10	10	10	10
5S	3f	10	10	10	10	10

The results after 30 months of exposure were basically the same as the results after 27 months of exposure, with a slight decrease in two of the delamination readings. Two of the six AI 2024-T3 panels treated with the modified primer DTM, are beginning to show signs of failure with ratings of 8 and 9. In addition, with the AI 2024-T3 panels treated with the regular primer DTM, the delamination value is now 4.5, with five of the six panels receiving ratings from 2 to 6.

3.8.12 South Florida Exposure After 33 Months

Table 25 summarizes the results after 33 months of exposure. The visual color change was rated at 3f for all. Blistering was noted and graded ranging from 6f to 10. Delamination was measured at 10 for all of the specimens except for specimen 2M, which had a delamination of 9.3 and specimen 2P, which had a delamination of 4.

In the areas of cracking, blistering, and scribe rust, the results after 33 months remain unchanged from the results after 30 months of exposure. However, with respect to color change, all of the panels now have a rating of 3f. Also, the delamination ratings for the AI 2024-T3 panels treated with DTM decreased slightly. For the AI 2024-T3 panels treated with the modified primer DTM, two of the six panels failed the delamination testing with ratings of 8, changing the delamination reading from 9.5 to 9.3. In the AI 2024-T3 panels treated with the regular primer DTM, five of the six panels now have ratings between 2 and 4, which would give a delamination value of 4.

Table 25. Florida exposure at 33 months.

Specimen ID	Color Change	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed	Asterisk (Failed)
1A	3f	10	6.7	2.1	10	—
1D	3f	10	9	2.1	10	—
1M	3f	10	10	2.1	10	—
1P	3f	10	10	2.1	10	—
1R	3f	10	9.3	2	10	—
1S	3f	10	6.3	2	10	—
2A	3f	10	10	10	10	—
2D	3f	10	10	10	10	—
2M	3f	10	10	10	9.3	—
2P	3f	10	10	10	4	—
2R	3f	10	10	10	10	—
2S	3f	10	10	10	10	—
5A	3f	10	10	10	10	—
5D	3f	10	10	10	10	—
5M	3f	10	10	10	10	—
5P	3f	10	10	10	10	—
5R	3f	10	10	10	10	—
5S	3f	10	10	10	10	—

3.8.13 South Florida Exposure After 36 Months

Table 26 summarizes the results after 36 months of exposure. The visual color change was rated as 3f for all. Blistering was noted and graded ranging from 6M to 10. Delamination readings range from 3.3 to 10, where 3.3 = severe to moderate and 10 = none. Face rust ranges from 8.9 to 10.

With regard to color change, cracking, and scribe rust, the results did not change significantly from 33 to 36 months. In addition, all of the steel panels failed their scribe rust testing.

Table 26. Florida exposure after 36 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	3f	9.6	10	6.7	2.1	10
1D	3f	10	10	9	2.1	10
1M	3f	10	10	10	2.1	10
1P	3f	10	10	10	2.1	10
1R	3f	9.9	10	9.3	2	10
1S	3f	8.9	10	6M	2	9.7
2A	3f	10	10	10	10	10
2D	3f	10	10	10	10	10
2M	3f	10	10	9.7	10	7.3
2P	3f	10	10	10	10	3.3
2R	3f	10	10	10	10	9.9
2S	3f	10	10	10	10	10
5A	3f	10	10	10	10	10
5D	3f	10	10	10	10	10
5M	3f	10	10	10	10	9.9
5P	3f	10	10	10	10	10
5R	3f	10	10	10	10	10
5S	3f	10	10	10	10	10

However, in the face-rust ratings on the CRS 1080 panels, all of the Sherwin Williams panels failed with ratings from 7 to 9, for an overall rating of 8.9; four out of 12 of the Hentzen panels are beginning to show signs of failure with ratings of 9, for an average of 9.6; and one of 12 Spraylat panels is beginning to show signs of failure with a rating of 9, for an average of 9.9.

The delamination ratings also changed. Three of 12 CRS 1080 panels treated with KemAqua by Sherwin Williams are beginning to show signs of failure with ratings of 9, for an overall rating of 9.7. On the Al 2024-T3 panels, five of six of the modified DTM panels failed with ratings between 4 and 9, for an overall rating of 7.3; all of the regular DTM panels failed with ratings between 1 and 9, for an overall rating of 3.3; and one of 12 of the Spraylat panels is showing signs of failure with a rating of 9 and an overall rating of 9.9 on the delamination testing. On the Al 5083-H231 panels, one of six of the regular DTM panels failed delamination testing with a rating of 9, which gives an overall rating of 9.9.

With regards to blistering, all of the CRS 1080 panels treated with KemAqua by Sherwin Williams failed the blistering testing with a 6M rating. Also, on the CRS 1080 panels, 10 out of 12 Hentzen panels, three of 12 control panels, and two of 12 Spraylat panels also failed the blistering tests with ratings of 6M, for overall ratings of 6.7, 9, and 9.3, respectively. On the Al 2024-T3 panels treated with modified DTM, one of six panels failed the blistering tests with a rating of 6M, for an overall rating of 9.7.

3.8.14 South Florida Exposure After 39 Months

Table 27 summarizes the results after 39 months of exposure. The visual color change was rated at 3f for all. Blistering was noted and graded ranging from 6M to 10. Delamination measurements range from 2.7 to 10. Face rust measurements range from 8.6 to 10.

Table 27. Florida exposure after 39 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	3f	9.6	10	6.7	2.1	10
1D	3f	10	10	9	2.1	10
1M	3f	10	10	10	2.1	10
1P	3f	10	10	10	2.1	10
1R	3f	9.9	10	9.3	2	10
1S	3f	8.6	10	6M	2	9.7
2A	3f	10	10	10	10	10
2D	3f	10	10	10	10	10
2M	3f	10	10	9.3	10	7
2P	3f	10	10	10	10	2.7
2R	3f	10	10	10	10	9.8
2S	3f	10	10	10	10	10
5A	3f	10	10	10	10	10
5D	3f	10	10	10	10	10
5M	3f	10	10	10	10	9.8
5P	3f	10	10	10	10	10
5R	3f	10	10	10	10	10
5S	3f	10	10	10	10	10

With regard to the face rust on the CRS 1080 panels, the results were the same after 39 months as the results after 36 months.

With respect to the blistering on the CRS 1080 panels, all of the Sherwin Williams panels failed with ratings of 6M; 10 of 12 Hentzen panels failed with ratings of 6M for an overall rating of 6.7; three of 12 control panels failed with 6M ratings for an overall rating of 9; and two of 12 Spraylat panels failed with 6M ratings for an overall rating equal to 9.3.

With respect to blistering on the AI 2024-T3 panels, one of six of the modified DTM panels failed with a rating of 6M for an overall rating of 9.3. In the delamination testing on the CRS 1080 panels, three of 12 Sherwin Williams' panels failed with ratings of 9 for an overall rating of 9.7.

In the delamination, testing on the AI 2024-T3 panels, five of six of the modified DTM panels failed with ratings of 4–9 for an average of 7; all of the regular DTM panels failed with ratings of 1–7 for an average of 2.7; and one of 12 of the Spraylat panels failed with a rating of 8 for an overall rating of 9.8. In the delamination testing on the AI 5083-H231 panels, one of six of the regular DTM panels failed with a rating of 9 for an overall rating equal to 9.8.

3.8.15 South Florida Exposure After 42 Months

Table 28 summarizes the results after 42 months of exposure. The visual color change was rated as 3f for all. Blistering was noted and graded ranging from 6M to 10. Delamination measurements range from 2.6 to 10. Visual color change, blistering, and delamination remained unchanged from 39 to 42 months.

Face rust measurements range from 8.6 to 10. With regard to face rust ratings on the CRS 1080 panels, four out of the 12 of the Hentzen panels failed with ratings of either 8 or 9 for an overall rating of 9.6; one out of the 12 of the Spraylat panels failed with a rating of 9 for an overall rating of 9.9; and all of the Sherwin Williams panels failed with ratings from 7 to 9 for an overall rating of 8.6.

Table 28. Florida exposure after 42 months.

Specimen ID	Color Change	Face Rust Unwashed	Crack Unwashed	Blisters Unwashed	Scribe Rust Unwashed	Delamination Unwashed
1A	3f	9.6	10	6.7	2.1	10
1D	3f	10	10	9	2.1	10
1M	3f	10	10	10	2.1	10
1P	3f	10	10	10	2.1	10
1R	3f	9.9	10	9.3	2	10
1S	3f	8.6	10	6M	2	9.6
2A	3f	10	10	10	10	10
2D	3f	10	10	10	10	10
2M	3f	10	10	9.7	10	6.8
2P	3f	10	10	10	10	2.6
2R	3f	10	10	10	10	9.8
2S	3f	10	10	10	10	10
5A	3f	10	10	10	10	10
5D	3f	10	10	10	10	10
5M	3f	10	10	10	10	10
5P	3f	10	10	10	10	9.8
5R	3f	10	10	10	10	10
5S	3f	10	10	10	10	10

Figures 7 and 8 are visual representations of steel coated panels exposed in Florida after 613 days.



Figure 7. Vendor after 613 days, 1S2 F2.



Figure 8. Control after 613 days, 1D4 F1.

3.8.16 Arizona Exposure

Exposure testing is performed in New River, AZ, (34° N), at a tilt angle of 5° from the horizontal facing south. The samples were mounted unbacked on a continuous exposure rack, with the green side facing the sun.

3.8.17 Arizona Exposure After 3 Months

Table 29 summarizes the results after 3 months of exposure. Visual color change, chalking, cracking, blistering, and crazing were all constant at 10. There were no failures after 3 months of exposure.

Table 29. Arizona exposure at 3 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	10	10	10	10	10	—
1D	10	10	10	10	10	—
1M	10	10	10	10	10	—
1P	10	10	10	10	10	—
1R	10	10	10	10	10	—
1S	10	10	10	10	10	—
2A	10	10	10	10	10	—
2D	10	10	10	10	10	—
2M	10	10	10	10	10	—
2P	10	10	10	10	10	—
2R	10	10	10	10	10	—
2S	10	10	10	10	10	—
5A	10	10	10	10	10	—
5D	10	10	10	10	10	—
5M	10	10	10	10	10	—
5P	10	10	10	10	10	—
5R	10	10	10	10	10	—
5S	10	10	10	10	10	—

3.8.18 Arizona Exposure After 6 Months

Table 30 summarizes the results after 6 months of exposure. Visual color change was rated as either 7f-DC or 7f, where 7 = slight to moderate, f = fade, and DC = discolor. Chalking, cracking, blistering, and crazing were all constant at 10. Color change ratings dropped from 10 to either 7f or 7f-DC. Except for color, there were no significant changes. There were no failures after 6 months of exposure.

Table 30. Arizona exposure at 6 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	7f-DC	10	10	10	10	—
1D	7f-DC	10	10	10	10	—
1M	7f-DC	10	10	10	10	—
1P	7f-DC	10	10	10	10	—
1R	7f-DC	10	10	10	10	—
1S	7f-DC	10	10	10	10	—
2A	7f	10	10	10	10	—
2D	7f	10	10	10	10	—
2M	7f	10	10	10	10	—
2P	7f	10	10	10	10	—
2R	7f	10	10	10	10	—
2S	7f	10	10	10	10	—
5A	7f	10	10	10	10	—
5D	7f	10	10	10	10	—
5M	7f	10	10	10	10	—
5P	7f	10	10	10	10	—
5R	7f	10	10	10	10	—
5S	7f	10	10	10	10	—

3.8.19 Arizona Exposure After 9 Months

Table 31 summarizes the results after 9 months of exposure. Visual color change was rated as either 7f-DC or 7f. Chalking, cracking, blistering, and crazing all remained constant at 10. The results after 9 months of exposure are the same as the results after 6 months of exposure. There were no failures after 9 months of exposure.

Table 31. Arizona exposure at 9 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	7f-DC	10	10	10	10	—
1D	7f-DC	10	10	10	10	—
1M	7f-DC	10	10	10	10	—
1P	7f-DC	10	10	10	10	—
1R	7f-DC	10	10	10	10	—
1S	7f-DC	10	10	10	10	—
2A	7f	10	10	10	10	—
2D	7f	10	10	10	10	—
2M	7f	10	10	10	10	—
2P	7f	10	10	10	10	—
2R	7f	10	10	10	10	—
2S	7f	10	10	10	10	—
5A	7f	10	10	10	10	—
5D	7f	10	10	10	10	—
5M	7f	10	10	10	10	—
5P	7f	10	10	10	10	—
5R	7f	10	10	10	10	—
5S	7f	10	10	10	10	—

3.8.20 Arizona Exposure After 12 Months

Table 32 summarizes the results after 12 months of exposure. Visual color change was rated at 5f-DC for all, where 5 = moderate to pronounced. Chalking, cracking, blistering, and crazing all remained constant at 10.

Color change dropped from 7f-DC to 5f-DC. However, the rest of the results remained the same, and there were no failures after 12 months of exposure.

Table 32. Arizona exposure at 12 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	5f-DC	10	10	10	10	—
1D	5f-DC	10	10	10	10	—
1M	5f-DC	10	10	10	10	—
1P	5f-DC	10	10	10	10	—
1R	5f-DC	10	10	10	10	—
1S	5f-DC	10	10	10	10	—
2A	5f-DC	10	10	10	10	—
2D	5f-DC	10	10	10	10	—
2M	5f-DC	10	10	10	10	—
2P	5f-DC	10	10	10	10	—
2R	5f-DC	10	10	10	10	—
2S	5f-DC	10	10	10	10	—
5A	5f-DC	10	10	10	10	—
5D	5f-DC	10	10	10	10	—
5M	5f-DC	10	10	10	10	—
5P	5f-DC	10	10	10	10	—
5R	5f-DC	10	10	10	10	—
5S	5f-DC	10	10	10	10	—

3.8.21 Arizona Exposure After 15 Months

Table 33 summarizes the results after 15 months of exposure. Visual color change was rated as 5f-DC for all. Chalking, cracking, blisters, and crazing all remained constant at 10.

The results after 15 months of exposure were exactly the same as the results after 12 months of exposure. There were no noted failures after 15 months of exposure.

3.8.22 Arizona Exposure After 18 Months

Table 34 summarizes the results after 18 months of exposure. Visual color change was rated as 4f-DC for all, where 4 = pronounced. Chalking was rated as 7, where 7 = slight to moderate. Cracking, blisters, and crazing all remained constant at 10.

After 18 months of exposure, color change ratings decreased from 5f-DC to 4f-DC. Also, all of the panels had pronounced chalking with ratings of 7.

Table 33. Arizona exposure at 15 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	5f-DC	10	10	10	10	—
1D	5f-DC	10	10	10	10	—
1M	5f-DC	10	10	10	10	—
1P	5f-DC	10	10	10	10	—
1R	5f-DC	10	10	10	10	—
1S	5f-DC	10	10	10	10	—
2A	5f-DC	10	10	10	10	—
2D	5f-DC	10	10	10	10	—
2M	5f-DC	10	10	10	10	—
2P	5f-DC	10	10	10	10	—
2R	5f-DC	10	10	10	10	—
2S	5f-DC	10	10	10	10	—
5A	5f-DC	10	10	10	10	—
5D	5f-DC	10	10	10	10	—
5M	5f-DC	10	10	10	10	—
5P	5f-DC	10	10	10	10	—
5R	5f-DC	10	10	10	10	—
5S	5f-DC	10	10	10	10	—

Table 34. Arizona exposure at 18 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	4f-DC	7	10	10	10	—
1D	4f-DC	7	10	10	10	—
1M	4f-DC	7	10	10	10	—
1P	4f-DC	7	10	10	10	—
1R	4f-DC	7	10	10	10	—
1S	4f-DC	7	10	10	10	—
2A	4f-DC	7	10	10	10	—
2D	4f-DC	7	10	10	10	—
2M	4f-DC	7	10	10	10	—
2P	4f-DC	7	10	10	10	—
2R	4f-DC	7	10	10	10	—
2S	4f-DC	7	10	10	10	—
5A	4f-DC	7	10	10	10	—
5D	4f-DC	7	10	10	10	—
5M	4f-DC	7	10	10	10	—
5P	4f-DC	7	10	10	10	—
5R	4f-DC	7	10	10	10	—
5S	4f-DC	7	10	10	10	—

3.8.23 Arizona Exposure After 21 Months

Table 35 summarizes the results after 21 months of exposure. Visual color change was rated as 4f-DC for all. Chalking was rated as 6 for all, where 6 = moderate. Cracking, blistering, and crazing all remained constant at 10.

The results after 21 months of exposure remained the same as those after 18 months of exposure, with the exception that the chalk ratings decreased from 7 to 6 for all of the panels.

Table 35. Arizona exposure at 21 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	4f-DC	6	10	10	10	—
1D	4f-DC	6	10	10	10	—
1M	4f-DC	6	10	10	10	—
1P	4f-DC	6	10	10	10	—
1R	4f-DC	6	10	10	10	—
1S	4f-DC	6	10	10	10	—
2A	4f-DC	6	10	10	10	—
2D	4f-DC	6	10	10	10	—
2M	4f-DC	6	10	10	10	—
2P	4f-DC	6	10	10	10	—
2R	4f-DC	6	10	10	10	—
2S	4f-DC	6	10	10	10	—
5A	4f-DC	6	10	10	10	—
5D	4f-DC	6	10	10	10	—
5M	4f-DC	6	10	10	10	—
5P	4f-DC	6	10	10	10	—
5R	4f-DC	6	10	10	10	—
5S	4f-DC	6	10	10	10	—

3.8.24 Arizona Exposure After 24 Months

Table 36 summarizes the results after 24 months of exposure. Visual color change was rated as 4f-DC for all. Chalking was rated as 5 for all, where 5 = moderate to pronounced. Cracking, blistering, and crazing all remained constant at 10.

The color change, cracking, blistering, and crazing ratings all remained unchanged from the results from 21 to 24 months. However, the chalk rating for all of the panels decreased from 6 to 5. In addition, in three of the six AI 2024-T3 panels for both the regular and modified DTM, slight delamination is occurring at the intersection of the 'X' scribe.

Asterisk is the total number of failures. Overall, three of the regular DTM and three of the modified DTM panels failed.

Table 36. Arizona exposure at 24 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	4f-DC	5	10	10	10	—
1D	4f-DC	5	10	10	10	—
1M	4f-DC	5	10	10	10	—
1P	4f-DC	5	10	10	10	—
1R	4f-DC	5	10	10	10	—
1S	4f-DC	5	10	10	10	—
2A	4f-DC	5	10	10	10	—
2D	4f-DC	5	10	10	10	—
2M	4f-DC	5	10	10	10	3
2P	4f-DC	5	10	10	10	3
2R	4f-DC	5	10	10	10	—
2S	4f-DC	5	10	10	10	—
5A	4f-DC	5	10	10	10	—
5D	4f-DC	5	10	10	10	—
5M	4f-DC	5	10	10	10	—
5P	4f-DC	5	10	10	10	—
5R	4f-DC	5	10	10	10	—
5S	4f-DC	5	10	10	10	—

3.8.25 Arizona Exposure After 27 Months

Table 37 summarizes the results after 27 months of exposure. Visual color change was rated as 4f-DC for all. Chalking was measured and rated as 5. Cracking, blistering, and crazing all remained constant at 10.

The results after 27 months are exactly the same as the results after 24 months, with the color change remaining constant at 4f-DC, the chalk remaining constant at 5, the asterisk, or total number of failures, remaining constant at 3 for both the regular and modified DTM on the AI 2024-T3 panels, and the cracking, blistering, and crazing all remaining constant at 10.

3.8.26 Arizona Exposure After 30 Months

Table 38 summarizes the results after 30 weeks of exposure. Visual color change was rated as 3f-DC for all, where 3 = pronounced to severe. Chalking was measured and rated at 4. Cracking, blistering, and crazing all remained constant at 10.

After 30 months of exposure, the color change ratings dropped from 4f-DC to 3f-DC. Also, the chalk ratings decreased from 5 to 4 for all of the panels, indicating a more pronounced chalk residue. In addition, three of the six AI 2024-T3 panels treated with modified DTM and six of the six (instead of three of the six) AI 2024-T3 panels treated with regular DTM are showing slight delamination at the intersection of the ‘X’ scribe.

Table 37. Arizona exposure at 27 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	4f-DC	5	10	10	10	—
1D	4f-DC	5	10	10	10	—
1M	4f-DC	5	10	10	10	—
1P	4f-DC	5	10	10	10	—
1R	4f-DC	5	10	10	10	—
1S	4f-DC	5	10	10	10	—
2A	4f-DC	5	10	10	10	—
2D	4f-DC	5	10	10	10	—
2M	4f-DC	5	10	10	10	3
2P	4f-DC	5	10	10	10	3
2R	4f-DC	5	10	10	10	—
2S	4f-DC	5	10	10	10	—
5A	4f-DC	5	10	10	10	—
5D	4f-DC	5	10	10	10	—
5M	4f-DC	5	10	10	10	—
5P	4f-DC	5	10	10	10	—
5R	4f-DC	5	10	10	10	—
5S	4f-DC	5	10	10	10	—

Table 38. Arizona exposure at 30 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	3f-DC	4	10	10	10	—
1D	3f-DC	4	10	10	10	—
1M	3f-DC	4	10	10	10	—
1P	3f-DC	4	10	10	10	—
1R	3f-DC	4	10	10	10	—
1S	3f-DC	4	10	10	10	—
2A	3f-DC	4	10	10	10	—
2D	3f-DC	4	10	10	10	—
2M	3f-DC	4	10	10	10	3
2P	3f-DC	4	10	10	10	6
2R	3f-DC	4	10	10	10	—
2S	3f-DC	4	10	10	10	—
5A	3f-DC	4	10	10	10	—
5D	3f-DC	4	10	10	10	—
5M	3f-DC	4	10	10	10	—
5P	3f-DC	4	10	10	10	—
5R	3f-DC	4	10	10	10	—
5S	3f-DC	4	10	10	10	—

3.8.27 Arizona Exposure After 33 Months

Table 39 summarizes the results after 33 weeks of exposure. Visual color change was rated as 3f-DC for all. Chalking was measured and rated at 4 for all. Cracking, blistering, and crazing all remained constant at 10.

The results after 33 months of exposure were exactly the same as the results after 30 months of exposure.

Table 39. Arizona exposure at 33 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	3f-DC	4	10	10	10	—
1D	3f-DC	4	10	10	10	—
1M	3f-DC	4	10	10	10	—
1P	3f-DC	4	10	10	10	—
1R	3f-DC	4	10	10	10	—
1S	3f-DC	4	10	10	10	—
2A	3f-DC	4	10	10	10	—
2D	3f-DC	4	10	10	10	—
2M	3f-DC	4	10	10	10	3
2P	3f-DC	4	10	10	10	6
2R	3f-DC	4	10	10	10	—
2S	3f-DC	4	10	10	10	—
5A	3f-DC	4	10	10	10	—
5D	3f-DC	4	10	10	10	—
5M	3f-DC	4	10	10	10	—
5P	3f-DC	4	10	10	10	—
5R	3f-DC	4	10	10	10	—
5S	3f-DC	4	10	10	10	—

3.8.28 Arizona Exposure After 36 Months

Table 40 summarizes the results after 36 months of exposure. Visual color change was rated as 3f-DC for all. Chalking was measured and rated as 3 for all. Cracking, blistering, and crazing all remained constant at 10.

After 36 months of exposure, the chalk rating decreased from 4 to 3 for all of the panels, while color change, cracking, blistering, and crazing remained constant. However, six of 12 AI 2024-T3 control panels, three of six AI 2024-T3 panels treated with modified DTM, six of six AI 2024-T3 panels treated with regular DTM, three of 12 AI 2024 panels treated with KemAqua by Sherwin Williams, one of six AI 5083-H231 panels treated with modified DTM, three of six AI 5083-H231 panels treated with regular DTM, and four of 12 AI 5083-H231 panels treated with KemAqua by Sherwin Williams are all showing slight delamination at the intersection of the 'X' scribe.

Table 40. Arizona exposure at 36 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	3f-DC	3	10	10	10	—
1D	3f-DC	3	10	10	10	—
1M	3f-DC	3	10	10	10	—
1P	3f-DC	3	10	10	10	—
1R	3f-DC	3	10	10	10	—
1S	3f-DC	3	10	10	10	—
2A	3f-DC	3	10	10	10	—
2D	3f-DC	3	10	10	10	6
2M	3f-DC	3	10	10	10	3
2P	3f-DC	3	10	10	10	6
2R	3f-DC	3	10	10	10	—
2S	3f-DC	3	10	10	10	3
5A	3f-DC	3	10	10	10	—
5D	3f-DC	3	10	10	10	—
5M	3f-DC	3	10	10	10	1
5P	3f-DC	3	10	10	10	3
5R	3f-DC	3	10	10	10	—
5S	3f-DC	3	10	10	10	4

3.8.29 Arizona Exposure After 42 Months

Table 41 summarizes the results after 42 weeks of exposure. Visual color change was rated as 3f-DC for all. Chalking was measured and rated as 3 for all. Cracking, blistering, and crazing all remained the same at 10.

The results after 42 months of exposure are exactly the same as the results after 36 months of exposure.

Table 41. Arizona exposure at 42 months.

Specimen ID	Color Change	Chalk Unwashed	Crack Unwashed	Blisters Unwashed	Craze Unwashed	Asterisk (Failure)
1A	3f-DC	3	10	10	10	—
1D	3f-DC	3	10	10	10	—
1M	3f-DC	3	10	10	10	—
1P	3f-DC	3	10	10	10	—
1R	3f-DC	3	10	10	10	—
1S	3f-DC	3	10	10	10	—
2A	3f-DC	3	10	10	10	—
2D	3f-DC	3	10	10	10	6
2M	3f-DC	3	10	10	10	3
2P	3f-DC	3	10	10	10	6
2R	3f-DC	3	10	10	10	—
2S	3f-DC	3	10	10	10	3
5A	3f-DC	3	10	10	10	—
5D	3f-DC	3	10	10	10	—
5M	3f-DC	3	10	10	10	1
5P	3f-DC	3	10	10	10	3
5R	3f-DC	3	10	10	10	—
5S	3f-DC	3	10	10	10	4

4. Summary

Laboratory results and a wide range of data exist for the four different systems and five substrates. The results show dependence on many factors, including substrate/material coating thickness. Pretreatment performances vary among alloys. So far, the replacements are similar in performance to the control DOD-P-15328 wash primer, and the results are very promising. Of course, no single laboratory test can provide all the answers.

Affected installations, facilities, and weapons systems will include all tactical combat vehicles, U.S. Army aviation helicopters and equipment, and depots that are currently looking for viable alternative hexavalent chromate free wash primers.

The elimination of hexavalent chromium and much of the solvent in wash primer would have a direct positive impact on worker health and safety. It will eliminate 12,600 lb of zinc chromate, 16,800 gal of package solvents, and 18,900 gal of thinner solvents emitted annually from DOD-P-15328. In addition, it will help to eliminate the need to dispose of 6,000,000 lb of CARC-stripped wastes as hazardous wastes.

At this point, the major challenge is to reconcile the differences observed between accelerated weathering and the natural world. The final natural environmental testing will be compared to the simulated, controlled laboratory results.

Figure 9 represents fielded DOD-P-15328 wash primer system, and figures 10–11 represent fielded water-reducible wash primer system. Both systems were coated 12-08-04.



Figure 9. DOD-P-15328 wash primer system; units were painted 8 December 2004.



Figure 10. Water-reducible wash primer system; units were painted 8 December 2004.



Figure 11. Water-reducible wash primer system; painted 8 December 2004.

4.1 Field Validation

Tests are required on military equipment to validate the completed laboratory and controlled testing. The ultimate objective of the process is to demonstrate that the low-VOC wash primers can provide a “drop-in” solution to the environmental issues associated with the solvent-based primer currently in use and provide equal or better performance, involving no significant changes to the application and stripping procedures currently being used.

The field demonstration of this coating was tested on a Patriot truck unit, with serial number 630106, at Letterkenny Army Depot (LEAD) facility. The unit is an engagement control station (ECS). The ECS is the only manned station in the battery during the air battle and is the operations control center of the Patriot battery. The ECS contains the weapons control computer (WCC), man/machine interface, and various data and communication terminals. Its prime mover is a 5-ton tactical cargo truck.

4.2 Objective

The primary objective is to demonstrate that the new wash primer meets or exceeds performance levels of the current wash primer and involves no significant changes to the application and stripping procedures currently being used when the primer is applied to hardware to be deployed in the field. The demonstration will validate that the new wash primers can be applied and stripped utilizing existing equipment and processes at the depots.

4.3 Equipment

4.3.1 Demonstration Setup, Commencement, and Operation

There are no special site-preparation activities, including equipment set-up, analytical instrumentation and required utilities when the substitute wash primers are applied.

The Patriot shelter unit is primarily aluminum on the sides. The aluminum sides have been patched where necessary and sealed with Bondo-type fillers. All sections of the aluminum sides on curbside rear and roadside front were replaced. These replacement surfaces were treated with alodine prior to positioning on the shelter. The corner brackets, steps, side brackets, and corner loop/“O” rings are steel, and they were welded or bonded to the unit using a polysulfide sealer. The air conditioned unit was previously primed and top-coated with CARC, Tan 686A, and all electrical areas were marked with cardboard and scotch tape.

The surface preparation requires sponge blasting of the entire surface. Prior to painting, the spot rust was hand sanded. The entire surface was blown down with compressed air. The top, bottom, and two brackets of the air conditioning shelf were not blasted. This is a standard practice depending on the condition at the time of overhaul.

4.3.2 Equipment

The spray equipment included a Binks Model 7 conventional gun, attached to a pressure pot at 10 psi and 60 lb air pressure at the spray gun. The room was conditioned initially at 78 °F and 50% humidity.

The candidate wash primer was Sherwin-Williams Kem-Aqua, coded E61G520. A water-reducible wash primer does not contain hexavalent chromates and significantly minimizes potential emissions of VOCs and HAPs during coating operations. This new wash primer is water-borne acrylic emulsions with corrosion-inhibiting pigment, designed for use under MIL-P-53030A, the water-reducible, lead- and chromate-free epoxy primer.

Prior to application the wash primer was reduced by 25% volume with water and applied to the unit.

Note: The front of the shelter showed no visible defects, and overall appearance was good. There was noticeable contamination and minor separation on one side and also on one half of the backside of the shelter. It was basically isolated streaks that had a drip or spot-like appearance, indicating a possibility that the high-pressure wash had some oil contaminants. The visible contaminated spots were sanded with 150-grit paper, in some places with a disk drill sander, air blown, and then spot wiped with isopropyl alcohol. Sanded areas were re-touched with wash primer.

The white epoxy primer was supplied by Deft, Inc., per MIL-P-53030, component A, coded 44-W-7, lot no. 57946 and component B coded as lot no. 57947. The system atomized favorably to a smooth surface.

The topcoat was supplied by Hentzen Coatings per MIL-C-53039 (18), green 383, coded 8605GUZ-PA, lot no. 13K411. The system revealed no problems after application.

Note: The topcoat colors were supplied by Hentzen Coatings (exterior, MIL-C-53039, green 383), Sherwin Williams (exterior, MIL-C-53039, black and brown 383), and Crawford Labs (interior, MIL-PRF-22750 (19), sea foam green 24410).

4.4 Technical Performance Criteria

This alternate technology uses a single-component, HAP-free, low-VOC formulation that employs water for reduction and clean-up.

The same coating application and stripping equipment that is used for normal production were used for the demonstration. The number of employees, level of training, skill, and education is the same as normal production operation. The same level of Occupational Safety and Health Administration training is required, although the elimination of the HAPs makes these considerations less critical.

Issues involving maintenance that are any different from the current technology are not anticipated. Since the demo will coat full-sized defense equipment, there should be no scale-up issue.

4.5 Health and Safety

Due to the reduction in VOCs and elimination of HAPs, there is less potential environmental impact on personnel and the surrounding community than with the current technology. Safety requirements noted in all Depot Maintenance Work Requirements and other procedures must be adhered to.

Test Procedure

The following procedures were performed to support the demonstration test:

1. Prior to trial date, apply wash primer using LEAD paint equipment on test panels and other representative sample pieces. Apply wash primer, primer, and final coat to all sample pieces and test for overall paint thickness as well as adhesion.
2. Prior to testing verify that all safety requirements have been satisfied and on-site safety personnel are available if needed.
3. All materials will be supplied by LEAD with the exception of the wash primer which will be supplied by Sherwin Williams. ARL will coordinate the shipment of wash primer to LEAD.

4.6 Anomalies

ARL will fund repainting of the ECS up to \$7.5K for failures directly attributable to the wash primer within 2 years of the coating application date. Covered anomalies include major blistering, flaking, corrosion, or similar defects resulting from the wash primer's failure. This provides adequate protection for failure of the wash primer to epoxy primer bondline as a result of the wash primer pretreatment.

ARL assumes no responsibility for any anomalies caused by failure to meet application requirements/guidelines, exposure to environments outside of design parameters of the ECS or as a result of the primer or topcoat. Minor defects due to reasonable use, handling, and shipping of the ECS will also not be covered by ARL. Normal corrosion consistently found on Patriot hardware coated with existing wash primers will not be covered.

5. Results

The water-reducible wash primer treatment, Kem Aqua from Sherwin Williams, was demonstrated on a Patriot ECS no. 630106. The following notes the results of the trial:

1. Reducing the wash primer with water was within acceptable limits.
2. Application using existing paint guns was satisfactory.
3. Operators noted that material was easier to spray.
4. Lack of solvent smell was an improvement.
5. New wash primer does not show hard settling after mixing (an ongoing problem with the current acid wash).
6. Wash primer did not cover some spots where contamination was present. After scuff sanding spots with sandpaper and rubbing lightly with alcohol, wash primer was reapplied successfully. Painters reported similar problems and corrective action encountered with the current acid wash material.

Overall, the results of trial were a success (see figures 12–19). Additional data will be gathered after the trial unit is completed. The trial unit will finish the refurbishing process, camouflage pattern painting, and preparation for shipping from LEAD. The unit was shipped to Fort Bliss as a training unit in April 2005. All follow-up for overall paint performance will continue at Fort Bliss.

5.1 Panel Testing

Performance validation testing of Al 2024-T3, aluminum (chromate), and CRS panels were completed simultaneously at the site property. Off-site property and performance validation testing of panels was conducted at ARL.

The panels were subjected to accelerated corrosion exposure, salt fog ASTM B117, and cyclic corrosion exposure based on GM 9540P. Salt-spray resistance is based on procedures described in ASTM B117. This test is widely used by the paint industry as a quality control test and is not necessarily indicative of long-term performance of the coating. GM Standard Test 9540P is an accelerated cyclic corrosion test that was developed by the automotive industry to more accurately replicate long-term outdoor performance of coatings than the conventional salt-fog test. Panels were evaluated using ASTM D 1654 for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments and ASTM D 714 for Evaluating Degrees of Blistering of Paints. Figures 20–21 show results after exposure.

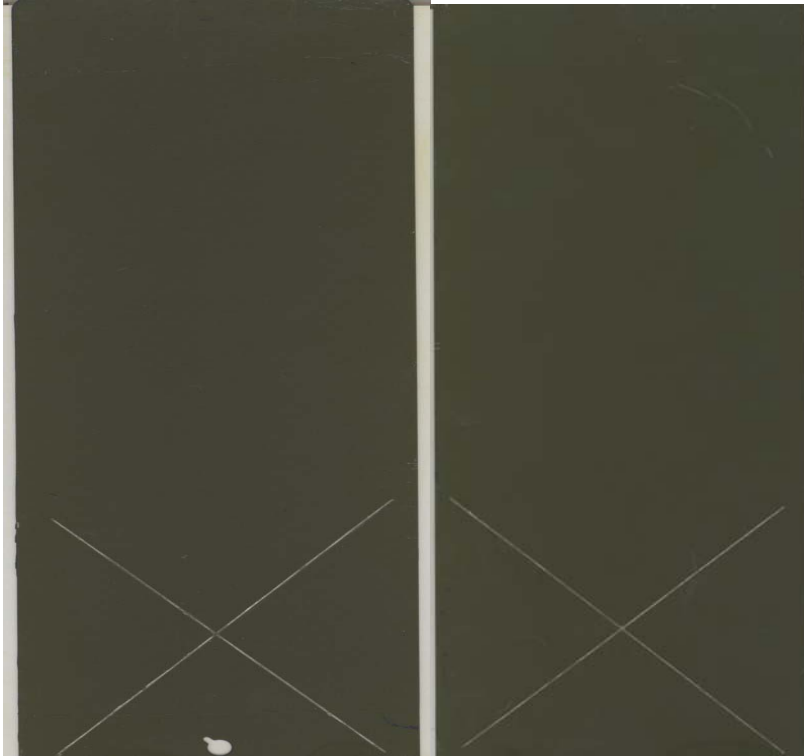


Figure 12. ASTM B117 (salt-fog results) aluminum test panels after 264-hr exposure.



Figure 13. ASTM B117 (salt-fog results) CRS panels after 264-hr exposure.



Figure 14. GM 9540 P (cyclic corrosion results) aluminum test panels after 10 cycles of exposure.



Figure 15. GM 9540 P (cyclic corrosion results) CRS test panel after 10 cycles of exposure.

Figures 16–21 depict replacement water-reducible wash primers. The panel without wash primer is on the left.



Figure 16. ASTM B117 after 1008-hr exposure. Steel panel without wash primer and with Sherwin Williams' KemAqua.



Figure 17. B-117 at 1008 DOD-P-15328.



Figure 18. GM 9540P at 35 cycles.



Figure 19. DOD-P-15328 at 40 cycles.



Figure 20. AL-2024-T3 GM 9540P at 1008 cycles.



Figure 21. Alclad Wp GM 9540P at 1008 cycles.

5.2 Post-Field Demonstration

Following completion of coating operations, the assigned unit will assess and report the status of the affected components as part of routine inspection. ARL will support in the disposition of any anomalies, including corrosion, flaking, blistering, chalking, cracking, or fading of the coating system.

Six months after the return of the ECS to its assigned unit, a team consisting of ARL, U.S. Army Armament Research, Development and Engineering Center (ARDEC), and Engineering, Environment, and Logistics Oversight Office (EELO) will travel to Fort Bliss to inspect and document the coating status of this hardware.

5.3 Field Visit to Fort Bliss

On 24 and 25 January 2006, a paint survey of Patriot vehicles was taken at the Lower Tier Project Office (LTPO), Fort Bliss facility located in El Paso, TX. The survey's intent was to inspect paint delamination at the seam line on an ECS that was coated with the revised wash primer and further document any paint defects on the other Patriot vehicles. Additionally, the survey would provide recommendations on materials and procedures to prevent, repair, and control observed damage. The following personnel participated in this effort as members of the Paint Survey Team (PST):

Pauline Smith (ARL), Kestutis Chesonis (ARL), Chuck Younger (AMCOM G-4), Al Aikman (AMCOM G-4), Nancy Whitmire (MRDEC), Terry Carmack (LEAD, Ft. Bliss), and Jonathan Salters (LTPO, Fort Bliss).

5.4 Survey Procedures

The survey of the Patriot vehicles was conducted through visual inspection. When possible, the PST members spoke with Patriot or military personnel regarding the personnel's observations of adhesion defects. Comments from personnel were recorded and are documented. Analytical equipment was used during the vehicle inspections to measure film thickness of coated areas adjacent to the delaminated, bare metal seam areas. PST members made written records of any paint defects, and photographs were taken of actual damaged areas. Representative paint chips were removed for laboratory analysis at ARL and at Aerospace Materials Function/Missile Research Development and Engineering Center (RDEC).

The Aerospace Materials Function/Missile RDEC analyzed the paint and polyester filler chips that were removed from the trial Patriot ECS unit. A cross section of both chips was prepared metallographically for inspection using a metallograph.

The micrographs presented in figures 22 and 23 depict the coating layers that are present on the paint chip. The top two layers appear to be black and green CARC topcoat. The third layer down

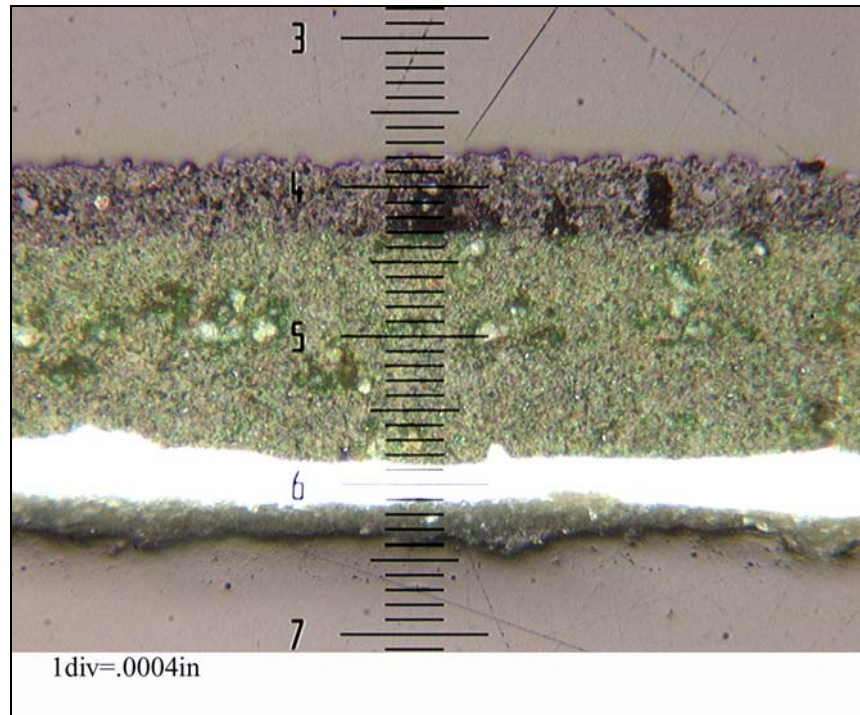


Figure 22. Micrograph of paint chip removed from Patriot ECS shelter with water-reducible wash primer.

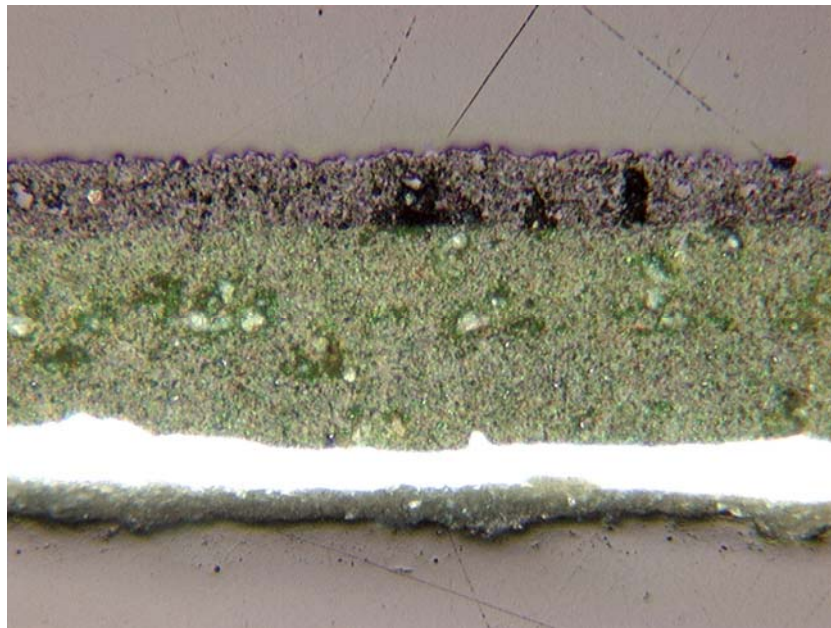


Figure 23. Micrograph of paint chip removed from Patriot ECS shelter with water-reducible wash primer.

appears to be a white primer, and the bottom layer appears to be the alternative wash primer (Sherwin Williams' Kem Aqua). No polyester filler appears to be present on the chip as noted by RDEC. In figure 22, each division of the ruler is equivalent to 0.0004 in. The average thickness of the alternative wash primer remaining on the chip is approximately 0.001 in.

Figure 24 is a micrograph of the polyester filler. It does not appear that any of the polyester filler material shown in figure 24 is present underneath the wash primer layer on the paint chip. The absence of any polyester filler on the paint chip indicates a lack of adhesion between the alternative wash primer and the polyester filler material.



Figure 24. Micrograph of polyester filler removed from the Patriot ECS shelter with water-reducible wash primer.

ARL analyzed samples of the paint chip; metallographic cross-sections of the coating samples were prepared in Bakelite. The coating system was cleanly fractured, mounted perpendicular to the fractured edge, and mechanically ground and polished through 0.02- μ m colloidal silica. The mounted cross-sections were then examined on a Nikon Epiphot 300 inverted metallograph. Digital micrographs were acquired from the coating system. The individual coating system layers were counted and their thickness was measured. Figures 25–27 present the coating system cross-sectional micrograph photos. The coating system can be observed within the mounting media which comprises the material at the top and bottom of the figures.

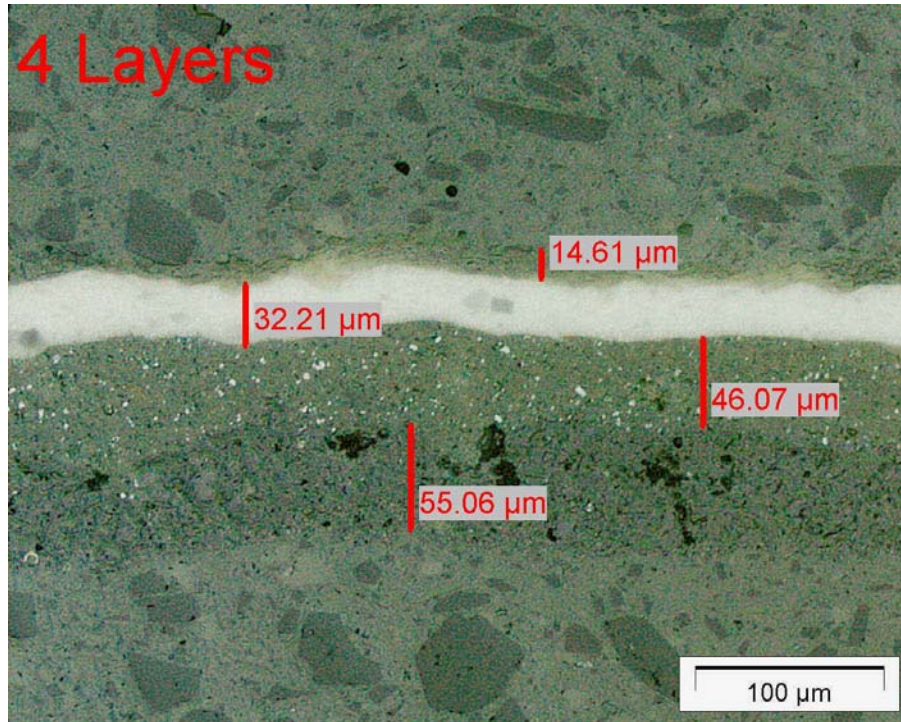


Figure 25. Micrograph of paint chip removed from Patriot ECS shelter with alternative wash primer.

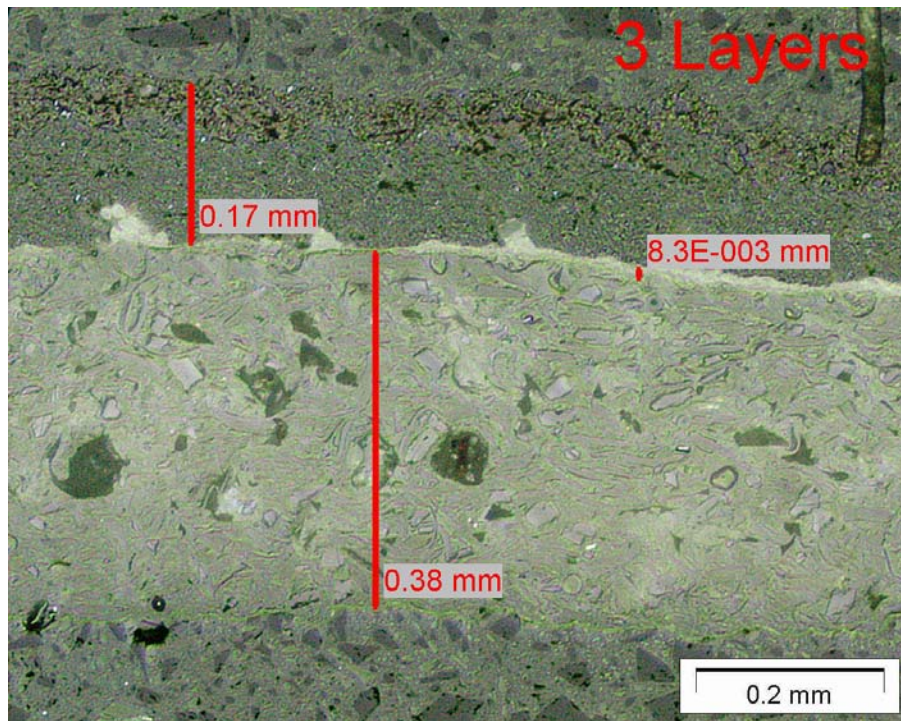


Figure 26. Micrograph of paint chip removed from Patriot CRG shelter with control wash primer.

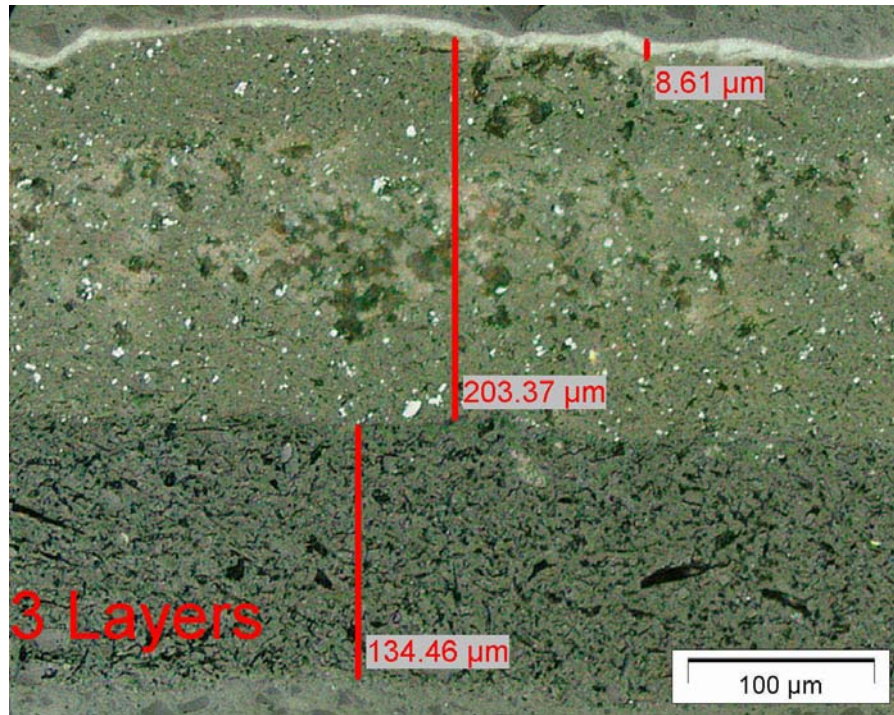


Figure 27. Micrograph of paint chip removed from Patriot ECS shelter with DOD-P-15328 wash primer.

The results of this analysis indicate an adhesive failure between the water-reducible wash primer and the polyester filler. Possible causes include material incompatibility between the water-reducible wash primer and the polyester filler or contaminants on the surface of the polyester filler prior to the application of the water-reducible wash primer. The paint chip from the new water-reducible wash primer showed four layers of coating while the control sample showed three coatings.

For the ECS serial no. 630106, overhaul date 05/05, there were two areas of paint adhesion failure on the outside of the vertical seam where the paint had peeled away or delaminated 1/4–1 in from the seam. Film delamination occurred only at the seam and only where the polyester filler was applied. Rivet head outlines could be seen along the entire seam. Expansion and contraction forces along the butt seam may be a contributing factor. This failure appears to be occurring at the weakest interface along the butt seam (i.e., between primer and body filler or substrate and body filler). Whatever forces are causing the flex of the substrate (evidenced by the rivet heads) distorts the coatings. The coatings are going to separate at the weakest interface, which appears to be the body filler/substrate interface (figures 28 and 29).



Figure 28. ECS before paint removal, serial no. 630106, overhaul date 05/05.

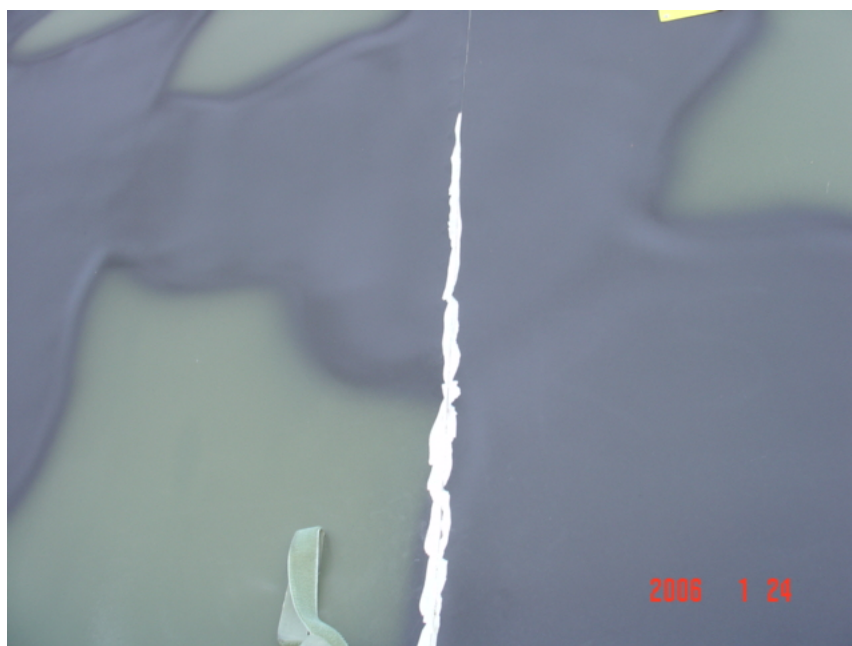


Figure 29. ECS after paint removal, serial no. 630106, overhaul date 05/05.

This Patriot ECS unit was painted using the low-VOC, water-reducible wash primer at Letterkenny, and fielded at Fort Bliss. The two areas of concern are sections of the shelter where the walls were replaced. The walls were bonded using a polysulfide sealer and polyester filler. The filler material appeared to have a heavy film. Dry film thickness measurements (1 mil = 0.001 in) were taken at four different areas. Data is recorded in table 42. Due to high temperatures, the shelter walls expanded causing the paint filler to crack and peel along the butt joints where replacement wall sections meet older wall sections. A knife blade easily removed painted filler along the edges for laboratory analysis.

Table 42. Dry film thickness (1 mil = 0.001 in).

Painted Area	Dry Film Thickness (mil)		Painted Area
	Body Filler + Filler + Paint	Filler + Sealer	
7.10	19.90	4.25	7.70
7.21	17.10	4.25	6.86
8.33	21.90	3.66	6.86
7.46	13.80	1.63	9.50

The Communications Relay Group (CRG) provides a multi-routed, secure, two-way data relay capability between assigned fire units and adjacent units. The CRG also provides the capability for both data and voice exit and entry point communications with elements external to the Patriot battalion.

There were areas of paint filler adhesion and damage to the exterior on CRG serial no. 620454, overhaul date 05/05 (figure 30). The paint and filler had peeled away or delaminated 1/4–1 in away from the seam, and the rivets also appeared loose. The paint, filler material, and sealant along the seam were removed. A knife blade easily removed paint and filler along the edges for laboratory analysis. This vehicle was painted with the current paint system but exhibited paint failure along the butt seam joint similar to the low-VOC wash primer trial unit.

6. Summary and Recommendations

The Military Specification on CARC System Application Procedures and Quality Control Inspection, MIL-C-53072C, does not address the use of any filler material with the CARC coating systems. The original intent was to evaluate the new wash primer over the aluminum bodied ECS. Bondo and fillers were not included as elements of the coating systems. Bondo Corp. manufactures various grades of polyester fillers. In the communications, the word “bondo” has become generic; the real filler used for this operation was made by Everseal.



Figure 30. CRG serial no. 620454, overhaul date 05/05.

In the automotive refinishing field, the polyester or peroxide filler type is the most common due to low cost and a fast curing rate. The major drawback is the substantial shrinkage that occurs with curing. Improved performing fillers devoid of shrinkage are two component epoxy systems with negative aspects of higher cost and much longer cure time before it can be sanded.

The legacy wash primer uses a vinyl butyral resin known for its adhesion to metal and glass and is admixed with phosphoric acid (3.67% of formula) prior to use. The new wash primers use an emulsion polymer and contain no free acids.

The butt seam repair process is employed where a damaged section of wall is cut out. A new wall section is cut to size, pre-treated, glued into place, and riveted down. The rivets are ground smooth; body filler is applied over the seam; and the body filler is then sanded smooth and feathered down on the edges to make the wall section smooth in appearance.

It appears that the construction method where a damaged wall section is cut out and replaced using a butt seam is a potential weak link where expansion and contraction can cause cracking or peeling at the weakest place.

No failures were noted on Small Repair Parts Transporter trailers. One major difference is that they don't use the butt seam construction method. They utilize lap seams, the rivets are not ground down, and no body filler is used; however, a seam sealant is applied to seal the lap seam.

In conclusion, an evaluation of the lap seam vs. the butt seam construction method should take place. It is too early to say definitively that the lap seam method will cure seam cracking, but this may offer a possible solution. A test utilizing a lap seam construction on an ECS or CRG is

recommended. It should be noted that out of all of the shelters, only two exhibited the butt seam cracking failure. Additional testing of the low-VOC wash primer on full-sized shelters would also assist in the overall data assessment. If additional testing is performed, some units with both the lap seam construction and the butt seam construction should be painted with the low-VOC wash primer.

This travel mission showed that the butt seam process on ECS and CRG shelters is a cause for concern with both paint systems (either the current acid wash pretreatment or the new low-VOC wash primer). One unit with a similar defect to the trial unit was found using the paint system with the current wash primer.

The coating system on the ECS was the water-reducible wash primer Kem Aqua supplied by Sherwin-Williams; epoxy primer was MIL-DTL-53030 supplied by DEFT and the topcoat was MIL-DTL-53039 supplied by Hentzen Coatings.

6.1 Post Field Visit

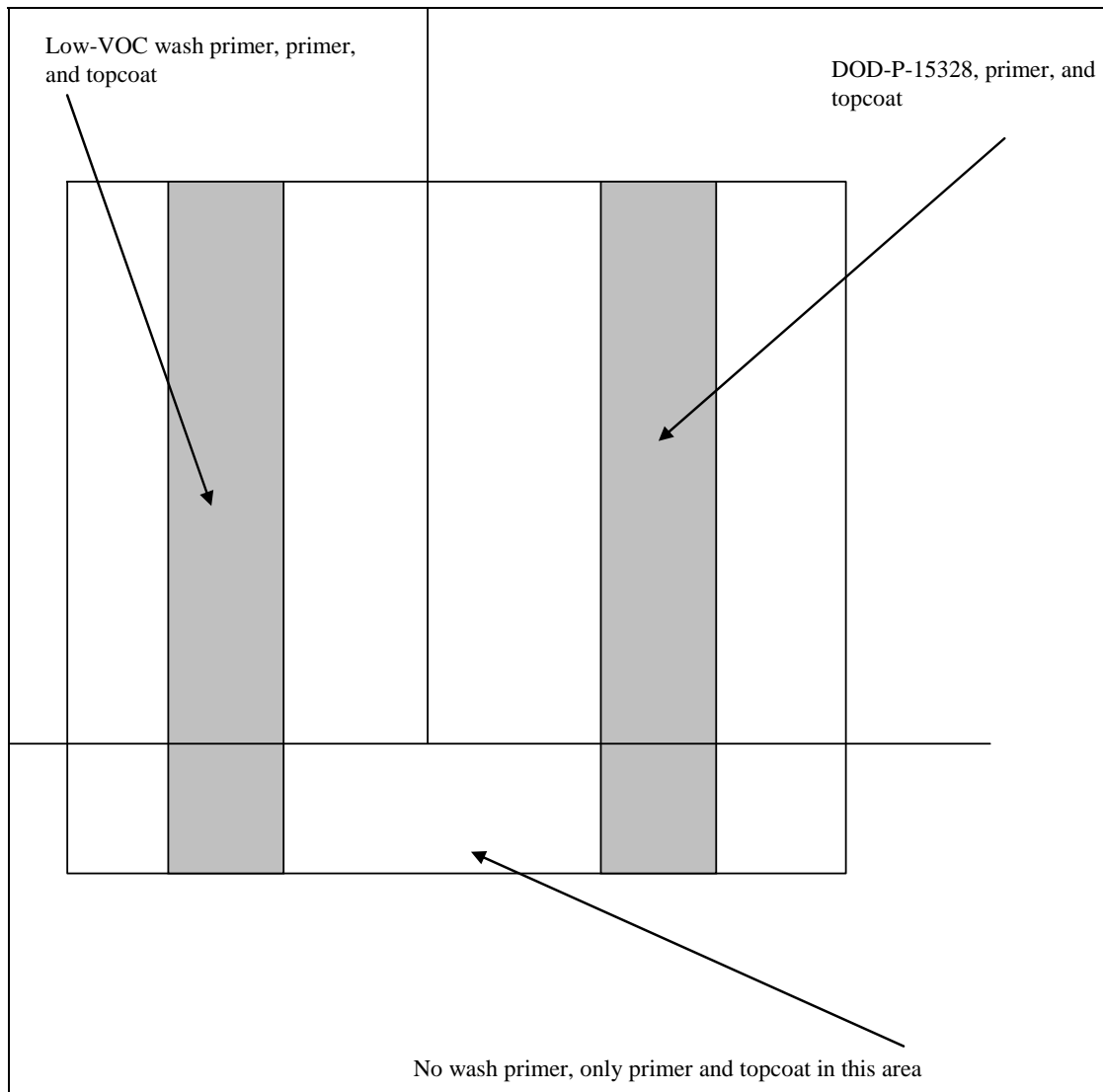
LEAD completed two seam sample pieces for the Patriot shelter reset repair and seam simulation. Masking tape was applied to separate the three areas: one seam with the current configuration (acid wash, primer, and topcoat); the other side with one seam with the new low-VOC wash primer, primer, and topcoat; and the bottom without wash primer. A small stencil marking will be applied in the corner of each region to identify the coating system (figures 31–33).

Figure 34 is the panel configuration showing the current configuration (DOD-P-15328, primer, and topcoat) on the left side. The low-VOC, water-reducible wash primer, primer, and topcoat are coated on the right side. The bottom seam is coated without any wash primer. All areas are overcoated with primer and topcoat.

Panels were exposed to high humidity (95%) and high temperature (71 °C) for a total of 90 days.

After 30 days, the water-reducible wash primer had three large blisters at the seam; DOD-P-15328 had one blister at the edge of the panel; DTM had one delamination, and the DTM coating system showed no adhesion when scraped with a spatula.

After 90 days of exposure, there were no further significant changes to the coating system. The water-reducible wash primer had loosened areas along its initial blisters; however, there was no further damage.



Note: Shaded areas represent seams with body filler feathered out.
 Area at the bottom is approximately 6 in wide.
 One-in masking tape will be applied where separation lines are shown. Masking tape will be removed after painting so a bare metal separation will show.
 One stencil marking will be applied in the corner of each of the three areas shown.

Figure 31. Test panel layout for new low-VOC wash primer.

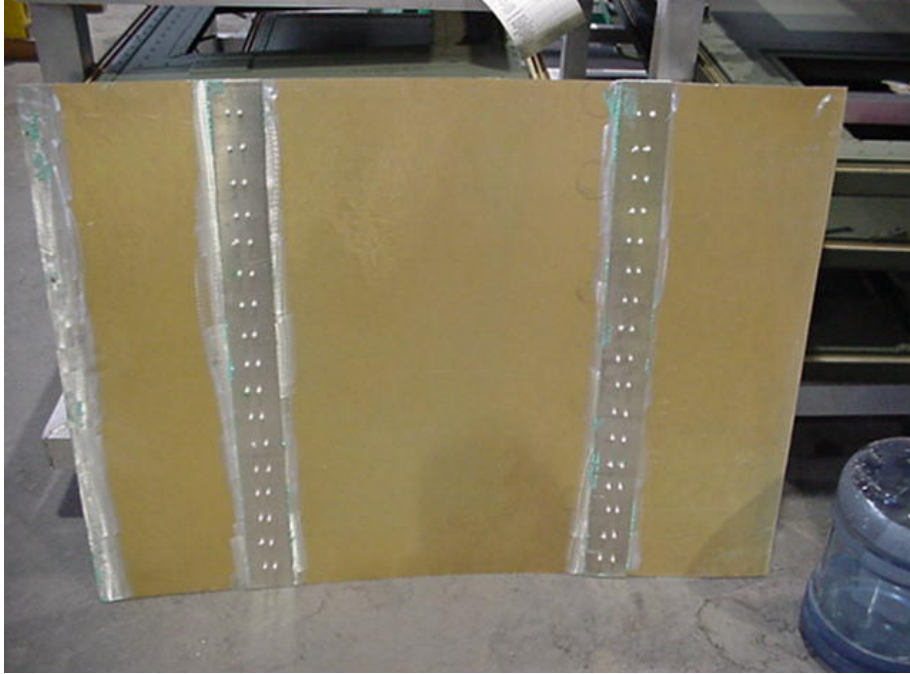


Figure 32. Three sections of aluminum panel joined by rivets.



Figure 33. After body filler is feathered out (just before coating application).



Figure 34. Panel simulation with three sections coated.

6.2 Results of Coating and Body Filler

The new wash primer was evaluated vs. current DOD-P-15328 wash primer system together with impacted areas of polyester filler material.

The systems were exposed to high humidity (95% and 70 °C) for 8 days. Following exposure, the exposed panels were tested for adhesion based on cross hatch adhesion testing per ASTM D 3359 Method B. There were severe to moderate failures exclusively on the (Bondo) filler areas, on both steel and aluminum substrates. Failure was more pronounced on the thin Bondo areas.

Both systems were immersed in water at room temperature for 7 days and tested for water immersion resistance using ASTM D1308. This involves exposing an organic coating to determine adverse affects. The coated panels were immersed halfway in deionized water at room temperature (23 ± 5 °C) for 7 days. The panels were examined for any defects such as blistering, loss of adhesion, color, and gloss change immediately following removal from the water bath.

Following water immersion exposure, the panels were tested for adhesion. There were severe-to-moderate failures exclusively on the Bondo areas on both steel and aluminum substrates. Failure was more pronounced on the thin Bondo filler areas.

In both cases, the systems with epoxy primer showed delamination between coats. The CARC topcoated systems showed delamination to the substrate.

Both systems were exposed in an accelerated weathering chamber for ultraviolet resistance. There were no changes in the coating system after 130 hr of exposure.

On 60% of the panels, heavy film of filler was apparent where it was applied on the dented area, however, the exact boundary of the feathering could not be discerned. This could explain the variations from moderate to severe failures. The polyester fillers tend to shrink upon curing, which is detrimental to the adhesion of the coating system.

The wash primers had very little influence on the adhesion problem. There were no differentiations on the old or new coating systems or on either steel or aluminum substrates.

7. General Conclusions

The CCCT at ARL analyzed data after 42 months of outdoor weathering of the specification DOD-P-15328 and water-reducible wash primers from three vendors. The new wash primers are water-reducible, formulated with corrosion inhibiting pigment, and are designed for use under MIL-P-53030, water-reducible, lead- and chromate-free epoxy primer. The coating system consisted of a wash primer coated with the epoxy primer MIL-P-53030 and CARC topcoat.

Panels were evaluated using ASTM D 1729 for Visual Appraisal of Color, ASTM D 714 for Evaluating Degrees of Blistering of Paints, ASTM D 2803 for Filiform Corrosion Resistance, ASTM D 661 for Evaluating Degree of Cracking of Exterior Paints, and ASTM D 610 for Evaluating Degree of Rusting on Painted Steel Surfaces.

The panels exposed to outdoor weathering in Florida and Arizona were terminated after 42 months based on coating failures. These panels were evaluated and photographed on site by Atlas Weathering Service. The exposed panels were also evaluated by ARL.

Without the wash primers, the panels showed severe coating delamination. Our recommendation is that aluminum panels of alloy 2024-T3 must be coated with the water-reducible wash primers, an inorganic conversion coating in accordance with MIL-PRF-5541, or DOD-P-15328. Data from both weathering sites showed that the usage of water-reducible wash primers or DOD-P-15328 on CRS Type R 1080 panels is not recommended.

These four systems were exposed to accelerated corrosion testing based on ASTM B 117 for 2088 hr and GM 9540P for 100 cycles. Panels were evaluated using ASTM D 1654 for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments and ASTM D 714 for Evaluating Degrees of Blistering of Paints. The criteria for failure was either creep from

scribe of greater than 10 mm (ASTM D 1654 rating of less than 3) or an ASTM D 714 rating for blistering in excess of 6M in the unscribed regions.

The results from neutral salt fog and GM 9540P cyclic corrosion exposures were complementary with minor differences. However, these accelerated exposures did not support the outdoor exposure data. Both laboratory results strongly supported the use of pretreatment on steel. This is a direct contradiction to outdoor exposure data in both Florida and Arizona.

The ASTM D 3359 cross-cut adhesion testing of unexposed panels on aluminum alloys 2024-T3 supported the use of the alternative wash primers. ARL plans to test additional panels using ASTM D 4541 for pull-off adhesion of coatings.

Using these water-reducible wash primers with MIL-P-53030 or similar water-reducible primer systems will provide an alternative to the DOD material (DOD-P15328). This will enable a hexavalent free coating system for aluminum alloys: 2024-T3, 5083-H131, 6061-T3, and 7075-T6.

Given that these water-reducible wash primers have been successfully tested and evaluated in the laboratory and outdoor weathering, the field demonstration was held to qualify the coating for implementation on fielded tactical equipment. The demonstration/validation of this coating at LEAD was initiated in February 2005 on an ECS Patriot unit (trailer) with serial no. 630106. The unit is currently fielded at Fort Bliss as a training unit.

A one year follow-up for overall paint performance to validate the application and durability of these products continued at Fort Bliss. This ongoing test demonstrated that the new wash primer meets the performance of the current wash primer when properly applied to tactical equipment deployed in the field.

ARL recommendation is to support the use of these alternative non-hexavalent chromate, water-reducible wash primers on aluminum alloys: 2024-T3, 5083-H131, 6061-T3, and 7075-T6, with MIL-P-53030 or a similar water-reducible primer system.

ARL does not endorse or support the use of a polyester filler material for use under any coating.

It will be required to establish repair procedures that exclude the use of such materials as the current alternative wash primers.

Current efforts are underway to revise DOD-P-15328, providing a QPL for the new product(s).

Additionally, revision of MIL-P-53030 to match the performance characteristics of new products currently in development will correspond with this initiative. Once DOD-P-15328 has been revised, the incorporation of the water-reducible wash primer products will be seamless for specific systems using the CARC coating.

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